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TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

SPECIAL MEETING, JUNE 19TH, 1888.

SUBJECT:

The Solution of the Municipal Rapid Transit Problem.

BY FRANK J. SPRAGUE.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

VOL. V. New York, August, 1888. No. 11.

SECRETARY'S BULLETIN.

The regular monthly meeting of Council was postponed until Friday, September 7th, on account of the conventions of the National Electric Light Association and the National Telephone Exchange Association.

On that date the following named gentlemen were elected to Associate membership, their applications having been properly endorsed:

James B. Williams, M.D., Oakland, Cal.
H. M. Byllesby, Pittsburgh, Pa.
Wm. H. Peirce, Aurora, Ill.
Charles Wirt, New York.
H. F Parshall, New York.
John X. Oatis, Amsterdam, N. Y.
O. B. Shallenberger, Pittsburgh, Pa.

On recommendation of the Board of Examiners, the following Associate Members were transferred to full membership:

Prof. W. E. Geyer, Hoboken, N. J. C. J. Van Depoele, Boston, Mass.
J. Howard Pratt, Jacksonville, Ill.

The meeting was subsequently adjourned to September 14th when the following named gentleman was elected to Associate Membership:

Ludwig Gutman, Fort Wayne, Ind.

It was also voted that the twenty-eighth meeting of the Institute, being the first of the present season, be held on October 9th, at which time a formal discussion will take place on the paper read by Mr. Frank J. Sprague, June 19th, on "The Solution of the Municipal Rapid Transit Problem."

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The twenty-seventh meeting of the American Institute of Electrical Engineers, was held in the Lecture Room, Library Building, Columbia College, Madison Avenue and 49th Street, New York, Tuesday, June 19th, 1888.

President WESTON called the meeting to order at 8 o'clock, P. M.

THE PRESIDENT:—Ladies and Gentlemen, and members of the Institute: We have with us to-night Mr. Frank J. Sprague, who will read a paper, entitled: "The Solution of the Municipal Rapid Transit Problem," or "Electricity and its Application to Electric Railroads." The matter is fraught with great interest, and as the system of electric railroads has about trebled inside of the last eleven months, it will undoubtedly be very interesting to hear of the work that Mr. Sprague has done in this direction. Few people who have not been engaged in working out experimentally the practical application of electrical appliances on a large scale, can appreciate the amount of labor, patience and perseverance required to bring them to such a state of usefulness as we see the electric railroad has reached. It not only requires that, but a great deal of money; both must be united to produce the desired results. I am sure we shall be pleased to hear what Mr. Sprague has to say, as I understand he has been very successful in overcoming many serious obstacles.

Mr. Sprague was received with applause and read the following paper:

THE SOLUTION OF MUNICIPAL RAPID TRANSIT.

BY FRANK J. SPRAGUE.

The presentation of this subject before the American Institute of Electrical Engineers for discussion seems to me most opportune. It is a question of great importance, and one for which a definite solution is fast becoming imperative. To those of us who believe that the solution is to be found in the application of electricity, it has a special significance, and I trust that what I say may bear fruit, by starting a general discussion of the subject, not only among electrical men but the general public as well.

More attention is now being paid to the question of tramway traffic than ever before. The reason is not only the comparatively high cost of operation under the present almost universal system of horses, but also because the public are beginning to feel, and the street railway men are beginning to see that it is a system behind the times. Laying all humanitarian questions aside the public demand a better and a more rapid service. Railway men want to give it, provided they can do so for the same or less money than they are now spending.

To quote from a New York evening paper:

"The rapid transit question has steadily pressed its way to the front of subjects demanding immediate attention, until it now stands in this city the foremost question of the hour.

"The fact is made evident, by the eager discussion upon every hand, of the very best means by which the end may be attained with the least possible delay. The total passenger traffic, that is, the total number of persons carried in this city, has increased at the rate of over 140 per cent. in each period of ten years since 1866, and is now something over 325,000,000. At the same rate of increase it would amount in 1890 to over 500,000,000, and in 1900 to 1,225,000,000."

There is every reason to believe that the through traffic will increase as much as expected, because the city is growing rapidly and its business section is continually enlarging and pushing northward, forcing the larger part of the population, especially the laboring classes, to seek homes in the upper portion of Manhattan Island and the Annexed District, where rents, already increasing because of the increased facility of access, are still lower than can be readily commanded for business purposes in the lower part of the city. The elevated roads of this city, although carrying 500,000 people a day, do not answer the requirements of rapid transit, either local or through; nor is it possible for any two-track railway to do so.

By rapid transit we do not mean merely through transit; we ought not to consider alone the methods of transportation from one end of the city to the other, or from the city to the suburbs; we are likewise called upon to find some means by which the local traffic shall be benefited. Everything which lessens cost of operation, increases speed, reduces intervals between cars, increases the number of cars and makes extensions possible, aids rapid transit, no matter whether surface, underground or overhead.

With the same cost of operation, provided the motive power is materially cheapened, a greater number of cars can be run, intervals can be shortened up, large cars can be run in the place of small ones, better attention can be afforded, cars can be better heated, lighted and cleaned; they can make better time, people can be carried further for the same money, branches can be opened in districts which would otherwise not pay, and what is all important, more passengers can be carried, and for this reason alone more money can be made. For years an attempt has been made to replace the horse with motors of various descriptions—compressed air engines, fireless engines, hot water and soda motors, naptha and petroleum engines and steam engines. But we can safely say that the question has to-day narrowed itself down as between the cable and the various electric systems for surface work, and between electricity and steam for elevated or underground work.

In order that we may be in a better position to judge of the comparative economy and the relative advantage of present and proposed methods of traction, I will briefly consider, first, the use of horses.

Two distinct methods are recognized among street car men in

the handling of their stable equipments. In one, the stock of horses is kept as low as possible; they are worked hard, making fourteen or fifteen miles a day, and the depreciation is very heavy. In the other the stable equipment is increased; the horses are kept in excellent condition; their average daily duty is reduced to ten or twelve miles, and the depreciation is lessened.

Assuming the cost of a horse as $150, and the cost of feeding and caring for him as $180 per annum, it would seem that any accurate knowledge of the average life of horses under different day's duty would soon determine the proper amount of the latter.

All railway returns do not, strange as it may seem, give accurate information on which such estimates of cost can be made; but from such facts as are given we may deduce the following: Taking the returns for 1887, for the five largest road sin Massachusetts, we find that they show 6,909 horses and 1,410 cars; that the mileage made was 12,834,665, and the passengers carried 76,187,842.

Dividing the average daily mileage by the number of horses, and multiplying the number of horses in a team, we find only 10.26 miles as the average daily duty for all teams, sick or well. Horses which are on duty make from 12 to 14 miles.

On the West End road of Boston, which is now the largest street railway combination in the world, having about 212 miles of track and over 8,000 horses, 10 per cent. of the horses are counted as being off duty from illness, sprains, shoeing or other causes; and the balance of the horses average about 12 miles a day. A car day is estimated at 10 to 11 hours, and from 45 to 50 miles, and eight horses are allowed as the active force.

The rule given me by one of the officials of this company, as a fair one to determine a stable equipment is, to divide the total daily mileage by the miles made in a car day and multiply it by nine, adding what is necessary for hill horses. Hence, if fifty miles is a car day duty, a daily run of 1,600 miles would require a stable equipment of 288 horses, besides those for hill work.

On the Fourth Avenue line in New York, the stable equipment is determined as follows: A car day is 11 hours, and eight horses make about five trips, aggregating about 50 miles. To this number is added 10 per cent. for illness, sprains, etc., and 10 per cent. for emergencies. On this road is illustrated the influence of an important factor in horse car work—that is, the position of the

stables. Horses from the upper stable are limited to 11 miles, or otherwise they would have to make 22 miles, while horses from the lower stable have to make about 13½ miles, or considerably more.

The average cost of motive power per car day throughout the United States, that is, for from ten to eleven hours and trips aggregating from forty-five to fifty miles, is about $4. This counts only those horses on actual duty on the road. The cost of motive power per car day for equal mileage in Richmond is less than $2 on the heaviest sort of grade work. The total operating expenses of a horse railway average for the five largest roads in Massachusetts 25.15 cents, and for all the roads in Massachusetts 24.7 cents per car mile; and the ratio of operating expenses to gross receipts is, for all the roads, 86 per cent.

The cost per day per horse, based upon the returns of four of the largest roads in New York, is 54 cents, and the cost per car mile from 9½ to 10½ cents per car mile.

In addition to the regular depreciation there is ever present danger of an epidemic in hot weather.

Since the cost of the motive power alone—that is, the cost of harness and stable equipments, horse-shoeing, renewals, provender, hostlers, etc.—is 40 per cent. of the total operating expenses, it will at once be seen how vitally important any material saving in the cost of motive power becomes. If, as we claim, the cost of motive power in an electrical system is one-half or less than that in a horse system, the percentage of gross receipts available for interest and dividends is more than doubled.

Furthermore, when we remember that the average running time for horses is only five to six miles per hour, we have another reason which constitutes an unwarrantable objection to the uses of horses for rapid transit.

Among the systems which have been proposed to take the place of horses and which has given the most promise, and met with the greatest success where heavy grades and traffic exist, is the cable system. With its general features you are probably familiar.

There are, however, a great many objections. One of the most serious is the great initial cost of the construction and plant, the cost of the conduit alone ranging anywhere from $50,000 to $80,000 per mile of single track, making the investment so large that none but roads having heavy traffic can permit of the expense.

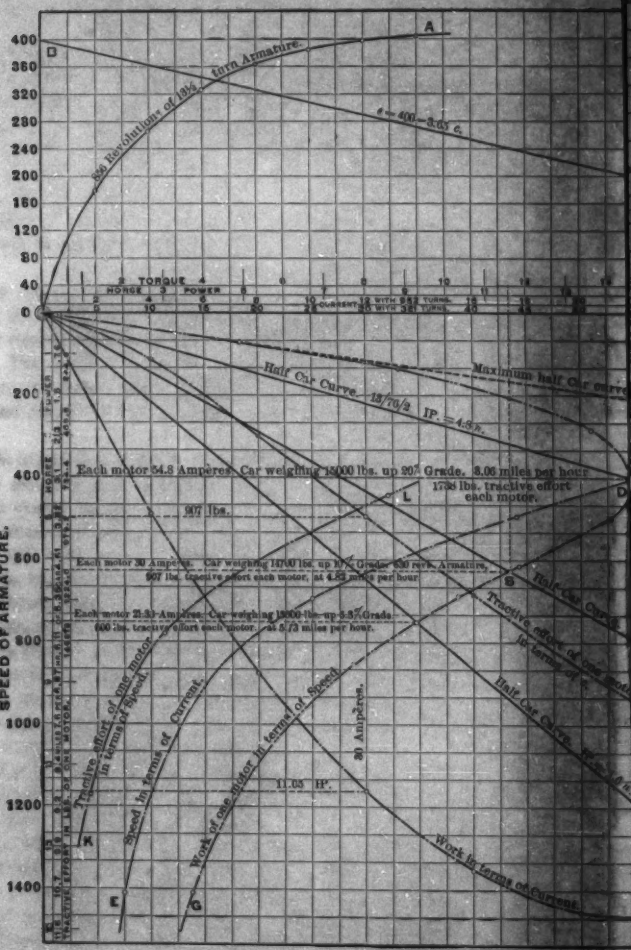
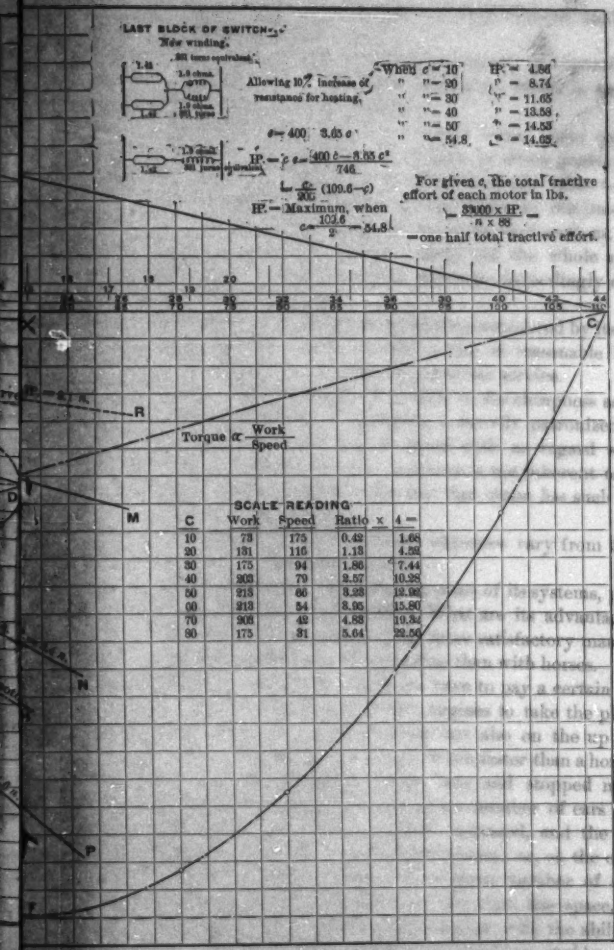


FIG. 1.—CURVES ILLUSTRATING ELECTRIC


LAST BLOCK OF SWITCH.
New winding.
.321 turns equivalent.
1.8 ohms (WIRE)
1.8 ohms (WIRE)
.321 turns
Allowing 10% increase of resistance for heating,
$e = 400 \quad 3.65\ c$
$HP. = \frac{e - 400\ c - 3.65\ c^2}{746}$
$= \frac{C}{2G}\ (109.6 - c)$
HP. = Maximum, when $c = \frac{109.6}{2} = 54.8$
When c = 10 HP. = 4.86
" " = 20 " = 8.74
" " = 30 " = 11.65
" " = 40 " = 13.58
" " = 50 " = 14.53
" " = 54.8 " = 14.65
For given c, the total tractive effort of each motor in lbs. $= \frac{33000 \times HP.}{.8 \times 88}$ = one half total tractive effort.
Torque $\propto \frac{\text{Work}}{\text{Speed}}$
C
R
M
N
P

C	SCALE READING Work	Speed	Ratio	x 4 =
10	73	175	0.42	1.68
20	131	116	1.13	4.52
30	175	94	1.86	7.44
40	203	79	2.57	10.28
50	213	66	3.23	12.92
60	213	54	3.95	15.80
70	205	42	4.88	19.54
80	175	31	5.64	22.56

RAILWAY MOTOR CHARACTERISTICS.

The conduit is necessarily large and costly in order to accommodate sheaves of sufficient size to prevent too great a loss in friction, and on account of the position of the cable and pulleys it is difficult to clean it. This large size also makes it difficult to construct a conduit which will not, because of the traffic and weather strains, be distorted and have the slots forced together or apart. The depth varies from two to three feet, more often the latter, and in any city street this is almost certain to interfere with steam, gas, or water pipes.

Each section of the line being a unit and operated from one cable, a break in the cable will suspend the entire traffic of that section.

A broken strand is apt to foul the grip and pile one car on top of another, as happened in Philadelphia, or suddenly start a car which is at rest, as recently happened on the 125th street line in this city. The cable is a heavy, cumbersome affair, 1¼ inches in diameter, and weighs about 13,000 pounds to the mile.

It is found that it is best to make these cables in 20,000 ft. lengths.

If a cable is stranded it cannot be used until repaired; if it is stretched 1 per cent. it is considered unsafe. These weaknesses of the cable system render it necessary to have a duplicate cable ready for instant use, and a double line of sheaves.

With a full load not over about 20 to 25 per cent, of the power of the engines is actually used for the propulsion of the cars, the balance being for moving the cable. With any light load the efficiency is even less, But it has been found advisable to have even greater power than this, most of the companies having from two to four times as much engine power as is required at any time, and from one and a half to twice the boiler power. This is necessary, because if any part of the cable engine breaks the whole section of the system is disabled.

Every turn in a cable brings a strain upon the grips and reduces the life of a cable, and any increase in the speed at which a cable is driven likewise shortens its life.

Difficulty exists in turning corners, expensive drums, and often times auxiliary cables being required. Constant care and attendance is necessary in lubricating the carrying and curve pulleys, and in taking care of the slots and switches—the estimates for Boston being about $3 20 per day per mile of single track, requiring the time of one man per mile. It is impossible

to work turnouts, crossovers or sidings without auxiliary cables, or to operate single tracks.

A line once being put in, any extension is expensive and difficult because of the terminal machinery which is necessary, and the definite length of the cable.

The speed is limited; a car cannot travel faster than the cable and thus recover lost time, except on down grades; nor can it travel more slowly save by permitting the cable to slip. The regular speed then, must be the same in the most crowded sections of the street as in the less populated sections.

The starting is often with a jerk, and the whole motion of a lurching, unequal, unpleasant character, exceedingly disagreeable when first experienced.

Success in the cable railway system considered by itself depends largely upon the condition that a line of reasonable length shall be so located as to warrant frequent car service.

The chief advantage of a cable is, the cheapness as compared with horse power, of operating a heavily patronized road at a comparatively fixed rate of speed with no regard whatever to grade or gravity; but this cheapness is not inherent to the cable system, but due rather to the fact that steam has such a tremendous advantage over horses.

The motive power operating expenses vary from 50 to 70 of the cost of operating by horses.

Now, what is it electricity, by some of its systems, promises us for the ordinary street traffic? What are its advantages? First it will do the work, and in a far more satisfactory manner and at a greatly lessened cost of operation than with horses. Electricity is simply an agent for which we have to pay a certain proportion to carry the power of our steam engines to take the place of the horse. Since not only on levels but also on the up and down grades an electric car can be run much faster than a horse car, and because it can be gotten under way and stopped much more quickly, the mileage with any given number of cars can be increased, the mean running speed increased, and the same time intervals made with a less number of cars; or, on the other hand, shorter intervals be made with a given number of cars. The equipment will occupy about 35 per cent. less space, the horse space being saved, and this fact, together with the ability to back when necessary, and to quickly gain headway, enables an electric car in narrow and crowded streets to work a passage through

where horse cars would be at a dead stand still. Not only can cars run down grade faster, but also with much more safety, because of the possibility of the instant reversal of the motors in the event of the parting of the brake chain; and when arriving at the top of a grade, the faster a motor runs the better. It has not got to be held in to save it.

The riding of an electrical car is far easier than that of any cable or horse car, starting and stopping more easily, and being in a large measure free from lurching and oscillation. The cars are much cleaner. They can be brilliantly lighted, and they can be heated by electricity. There is no dust such as rises from the heels of horses. The sanitary conditions are entirely altered, and the health and comfort of the whole population is conserved. Stables with all their unsavory characteristics and the consequent depreciation of the value of adjacent real estate disappear. No sand is needed on the pavements, and the pavements are not so quickly worn out; often no centre paving is necessary. It becomes feasible to operate branch lines, and also combinations of grades, curves, and ill-conditioned streets which would be prohibitory to any other system. It is not to be claimed that any one system of electric traction has all these advantages; but in some form or other they will be found.

It has been said that an extended system cannot be operated by electricity, that the lines may break down, that a large number of cars cannot be operated simultaneously, especially when bunched up, that wires burn out, that brushes burn up.

True, these things have happened, and in case of defective workmanship or carelessness they may happen again. Although electricity is a force of unknown nature, and we know it by its effects, it is folly to hold that whatever faults in machinery may exist or accidents occur they do not come within a very narrow and limited category; and powerful and mysterious as it is, and answering an impulse with the rapidity of lightning, it is at the same time the most tractable and law abiding agent with which we have to deal.

There is not a freak of which it is capable which we can not guard against. It has not an attribute of which we cannot make positive use. It has no power of damage which cannot be controlled.

The development of its application, the mistakes which have been made and the accidents which have occurred are but the milestones and guideposts of the highway to success.

Were it not for the occasional failures there would be no advance.

As a matter of fact there is no apparatus for the transmission of energy that compares in simplicity and efficiency with the dynamo-electric machine and the electric motor. There is no machine in existence which, when thoroughly and well built, and decently cared for, is less liable to get out of order, and will stand harder usage and greater variations of work with a minimum of attendance and care. A motor has but one moving part, and that has a rotary motion. Its torsional effort under given conditions is a constant, and when properly built and proportioned some types have over a wide range the remarkable and unique quality of having this torsional effort vary as the square of the current used, a feature of marked importance in traction work.

As modern as the motor is, the peculiarities of all its phases are just as well known and capable of just as graphic representation and forecast, as are those of the steam engine. This can best be shown by reference to some curves which illustrate the characteristics of some of the Richmond motors, and have the same significance that an indicator diagram has for an engine. They are partly theoretical, and in practice are somewhat changed, but are interesting as showing a graphic method of motor indication.

For convenience these curves are plotted on both sides of the axis of X. The ampère turns on one leg of the field magnet are plotted as abscissæ. The curve $O\,A$ gives the mean characteristic of the machine when run as a series dynamo on a variable external resistance at 856 revolutions. $B\,C$ represents the equation of counter-electromotive force with an initial electromotive force of 400 volts. I have allowed an increase in the actual resistance of the machine of 10 per cent. for heating and other causes. The speed of the armature, the miles per hour made by a car with the Richmond gearing, the tractive effort in pounds for one motor, and the horse-power units are, for convenience, all laid off as negative ordinates. Equal units of horse-power and torque are laid off as abscissæ, so as to make the maximum points coincident.

The first important curve which we have to get is the speed of the motor in terms of its current. We have the law that the speed is directly proportional to the counter-electromotive force developed, and inversely proportional to the strength of the field. In other words, the speed curve $E\,D\,C$, in terms of the current,

is plotted from the curves $O\,A$ and $B\,C$, and the speed for any current is found by multiplying 856 revolutions by the ratio of the ordinates corresponding to that current.

The next curve with which we have to deal is that of the work of the motor in terms of the current; that is, the curve $O\,F\,C$, which intersects the axis of X at the same point as the curves of speed in terms of the current and the counter-electromotive force line.

A third and most important curve is that of the work of the motor in terms of its speed, which is the curve $O\,D\,G$ plotted from the curves $E\,D\,C$ and $O\,F\,C$, with the horse-power units transferred to the axis of X as abscissæ. For instance, following the negative ordinate for 30 ampères, we find, at the proper intersection, a speed of 360 revolutions of the armature, or 4.82 miles per hour of the car; and, at the insection of the work curve, that 11.65 h. p. is developed. These two values give us the point S as one of the points of the work curve, and so on.

Referring to the work required to be expended on a car, we have from the formula—

$$\text{h. p.} = \frac{w\,n}{335}\left(\frac{k}{2000} \pm \sin\,\theta\right)$$

where w = wt. in lbs.

n = miles per hour,

k = resistance to traction in lbs. per ton on level,

θ = angle of grade,

the work which is required for any grade, speed and weight. Hence for any given conditions we can plot the equation h. p. $= a\,n$, and by its intersection with the curve $O\,D\,G$, find at what speed the car will be moved by the motors and what current is required if we know the gearing. On the other hand, if we assume that a certain load on a certain grade shall be handled, and we elect that it shall be done with a certain efficiency of the motor, or on a certain part of the work curve, we can draw the car curve for this intersection and then deduce the speed of the car and, from it, what must be the ratio of gearing to enable the car to be handled by the motors under these conditions. Four of such car curves are drawn—$O\,R$, which shows the maximum which could be moved; $O\,M$, which shows what can be done at 50 per cent. efficiency; $O\,N$ and $O\,P$, showing the equations which are constantly in practice.

In the actual computation 10 per cent. extra is allowed for losses from friction and so forth.

With the Richmond gearing, and a car equation of h. p. $= 4.8\ n$ we would have a car weighing 14,700 pounds sent up a 10 per cent. at 4.82 miles per hour, and each motor would take 30 amperes of current. If the grade or weight were increased, the curve $O\ N$ would be carried toward $O\ M$; or, if the ratio of gearing is changed, then with the curve $O\ N$ in its fixed position, the weight of car or grade could be increased, although the speed, of the car would be reduced. Other curves are shown, $L\ K$ showing the tractive effort of the motor in terms of its speed, and $O\ H$ showing the tractive effort in terms of the current; the tractive effort varying, of course, as the work divided by the speed.

The variety of problems which can be worked out from these curve sheets is very large, and they become of vital importance in dealing with any new work. Nothing could show more clearly the value of a mass of iron in the field magnets (as I have always held to be the proper method of building motors), and the exceptionable qualifications of motors for tractive purposes. Any change in the switch or any change in the potential will vary these curves materially. One fact, however, is to be noted; no matter how the field may be changed, the speed of the motor at 50 per cent, efficiency is nearly constant.

The connection of the motor to the driving wheels has been attempted in a great variety of ways, and nearly every mechanical device possible has been used. Often the motors are carried upon the car body and connection made with the wheels, which should bear a variable position relative to the car, by means of friction wheels, sprocket-wheels and chains, or by belts, ropes or wire-chains with tightening devices. The motor armature has been mounted directly on the axle, and also hung on a frame between the axles, being connected to both wheels by cranks and side rods, necessitating equal speeds of revolution of the motor armature and the wheels.

These methods are all crude and unsatisfactory. They are makeshifts and ignore the most important and essential facts which have been developed in car and motor construction. There is to my mind only one good way to connect a motor, and this is to centre the motor upon the axle, supporting it flexibly from the car body or the car truck, and driving by gearing with one or two reductions according to the service which is demanded. This is the only way in which an absolutely safe and positive

connection can be depended upon both for ordinary work and for the normal and sudden strains called for in an emergency.

Properly made, the friction of this method of reduction is very low, the motion is smooth and free, and reasonably noiseless.

The proposition to couple the motor so that it shall make the same number of revolutions as the axle ignores one of the most important points which makes light weight in motors possible, and that is the high speed at which the armature can be run.

I have pointed out, in describing the curve characteristics of a motor, one of the essentials to determine the proper ratio of reduction for any motor when required to do a given work. I may here add a brief formula, which will also serve as an index in this matter: Let f equal the maximum velocity in feet per minute at which an armature at any time is allowed to travel; n the number of miles per hour to be made by the car; D the diameter of the car wheel in inches; d the diameter of the armature in inches. Then the ratio of the gearing must be expressed by the equation.

$$R = \frac{f\,D}{88\,n\,d}$$

For instance, let $f = 4{,}000$, $n = 12$, $D = 30$ and $d = 10$; about the value which exist in street car work. Then

$$R = \frac{4{,}000 \times 30}{88 \times 12 \times 10} = \frac{125}{11}$$

and this should be made in two reductions. As in our largest trucks, let $f = 4{,}000$, $n = 35$, $D = 42$ and $d = 18$. Then

$$R = \frac{4{,}000 \times 42}{8 \times 35 \times 18} = \frac{100}{33}.$$

In the application of electricity we are limited to no one system; we have a choice which will permit us to meet any exigencies or conditions of traffic. There are two kinds of application.

In one, each car is perfectly independent of the other, receiving its charge at the central station and acting as an individual unit. The storage battery method is such a system.

The other is a system of direct supply, and, unlike the battery system, where the energy of the steam is four times converted, it suffers only two losses. In this system the current is delivered directly to the line, from which the motors as they move along derive their current. There are several forms of conductors, centre and side rails, the main tracks, conductors carried in conduits, and overhead. Either a complete metallic circuit may be used, or one conductor with the rail and earth return. The ma-

chines can be operated under three different systems—the series, multiple series and parallel circuit distribution.

Of these various plans, I shall discuss only three—the storage battery, the conduit and the single overhead wire system with underneath contact carried on the car, and for the systems of distribution the parallel circuit system only.

The storage battery from the time of its first introduction to the public has offered a tempting solution to the application of electricity for surface transit. The great advantage of the battery system is that while most of the advantages of an electric system are retained, such as perfect control of the car, ease of manipulation, cleanliness and so forth, each car in itself becomes an independent unit not dependent upon any general accident to a system. As attractive a solution as the storage battery at first sight seems, there are many points of disadvantage in the present state of its developement. One of the most important is the excessive weight of battery which is necessary under the conditions of service which are met with in this country, from 3,400 to 4,000 pounds being the ordinary weight. Not over 10 per cent. of the lead in these batteries is actually used for storage. On account of the weight and the room which the battery takes up, there has to be a radical change in the construction of the cars, and while old cars can be made use of by a great deal of patching, it is not advisable to attempt this. This change makes the present cars useless, and likewise increases the cost of new car bodies.

Then again, while the tracks as they exist may stand the additional weight of motors on a four-wheel car, the additional weight of battery, making the total weight on a given wheel-base double what it was before, will render it necessary on a great many tracks to relay the road-bed, or to put in 8-wheel cars. Of course these objections are not so serious on a new road as they are on an old one.

But I confidently expect to see in the not so very distant future, weight of battery necessary to handle a car reduced one-half; this, besides overcoming some of the objections which exist now, will halve the expense of handling them at the central station, and will also allow the present standard width of aisle to be maintained.

The present excessive cost and unknown depreciation of the battery, its lack of efficiency, limited capacity, the fact that only a portion of the charge can be taken out with safety, and the re-

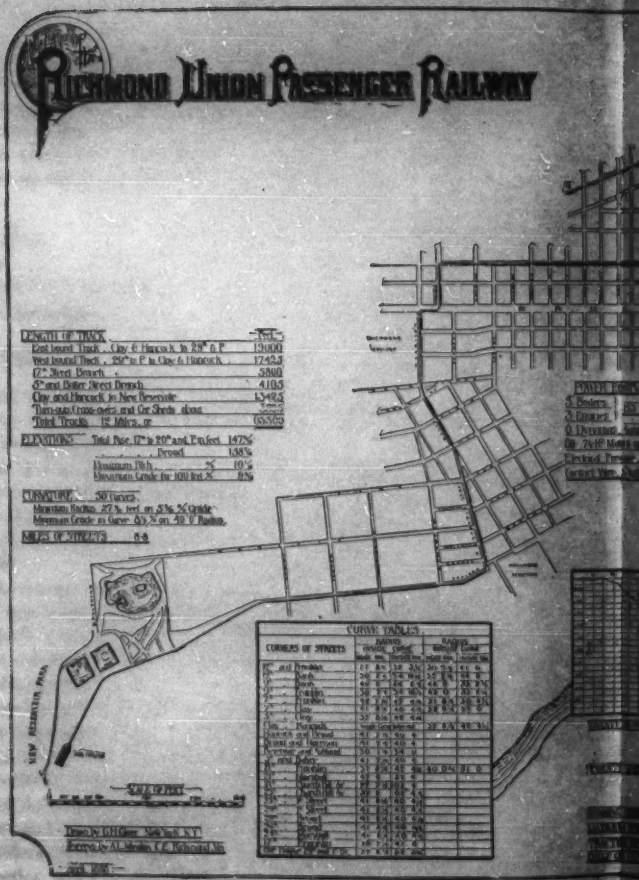
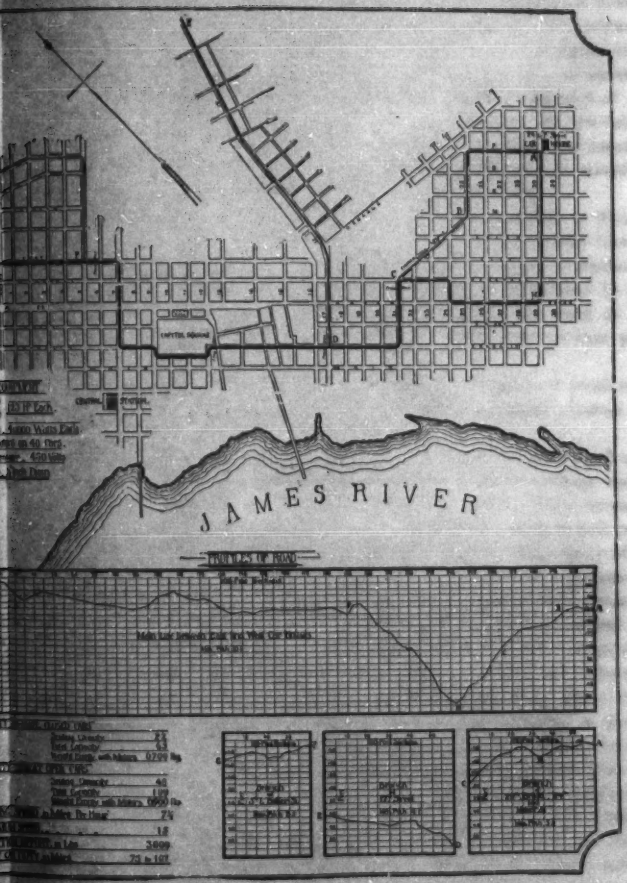


FIG. 2.—MAP AND DATE OF RI



ECTRIC RAILWAY, RICHMOND, VA.

duction of its output when sudden demands are made upon it, are all of such a character as to leave wide room for improvement. The loss of efficiency in conversion I do not esteem of such vast importance, because, in any large system where the engines are kept going under a steady load, the cost of operation will not be so very much more than where operating under continually varying loads. The limited rate of discharge, as well as the limited capacity, limits the grade work to which a battery car can be subjected. For instance, as batteries and cars are now made, we can easily have the following combinations of weight:

	Pounds.
Weight of car	5,000
Batteries	3,600
Motors and other apparatus	2,000
Sixty-five passengers	9,100
Total	19,700

To start and to accelerate this load on, say a 9 per cent. grade, demands a discharge rate which no storage battery company cares to recommend.

As near as it is possible for us to get at a correct estimate on a new road of moderate grades a storage battery system could be operated at about 80 per cent. of the cost of operation by horses. This is about double the cost of the direct system of supply on a large scale.

But the storage battery is not going to stand still.

Many men with abundant capital are striving for improvement, and I think there is but little question that batteries will be reduced in weight, increased in capacity, and made far more efficient and long-lived.

The conduit and overhead system have one point in common. Both are dependent upon a central station, and the actual cost of operation (except for the care and maintenance of the conduit itself) would be about the same. There is, however, a great difference of investment. Both must have about the same amoun of copper, and, to be effective, about the same distribution.

The difference of cost then is practically the difference betwee. pole erection and conduit laying, and this will be from $25,000 to $30,000 per mile. As an investment of course it means that with the conduit very much more money has to be earned. The

electrical conduit can be built for less money than a cable conduit, because it can be made of less depth, but it cannot be built without due regard to the strains of street traffic and weather, and with proper drainage and cleaning facilities. The advantages of the conduit are chiefly that there are no overhead obstructions. Its disadvantages are, besides its great cost, the lack of cleanliness, increased possibilities of leakage, and greater difficulty of repair in case of accident. Recognizing, however, the demand which exists in certain places for a conduit, we have developed such a system which has many of the same elements of simplicity and reliability that our overhead system possesses.

The working conductor carried in the conduit is divided into sections, which at intervals of every block or half block, as desired, are connected through automatic cutouts in manholes to the main conductor, which is continuous and enclosed in a lead or iron covered cable. Any accident to a section, such as flooding, short circuiting, and so forth, will simply cut out that particular block.

For the immediate solution of the question of more rapid and cheaper transit in many places the overhead system is most available.

I am aware that a great hue and cry has been raised, especially of late, against any electric wires whatsoever being used above ground. The feeling which exists is not entirely unreasonable; in fact it is easily accounted for by the most casual inspection of the condition of the wires of this city. But many of the objections which are raised against all overhead systems are not necessarily inherent; they are very largely due to gross carelessness in construction engendered by a faulty municipal administration. We have in our cities little or no active control or oversight of the wires which have been put up in our streets. Year after year, from the earliest telegraph days, those in control have granted to telegraph, electric light, telephone and electric power companies innumerable more or less limited franchises for stringing or hanging wires through our streets. These permits have often been granted without any restriction whatever; they are often granted for a "consideration." The erection and maintenance of these lines being a large factor in the cost of construction and operation of the companies, they have been put up with little or no regard to public convenience or safety—certainly with no regard to any æsthetic tastes—and often times with an

utter ignorance of the proper methods of construction. Fire-underwriters in their wisdom, have demanded an insulation to stand fire, forgetting, or in apparent ignorance of, the fact that protection from moisture and leakage is of far more vital impoetance. Hence we have that treacherous wire known as "underwriters' wire," or more commonly among electricians, "undertakers' wire."

The poles have until lately, been of the cheapest construction, badly set and continually marred and weakened by the spurs of the linemen. New lines have been continually added, and poles intended originally for a certain number of wires are now carrying double or treble that number.

The electric light companies, after cutting out a lamp for which a contract has expired, leave the bights of their wires hanging in loops. The telegraph and telephone companies allow thousands of miles of "dead" wires to remain overhead, or to hang in festoons from every pole, which in some sections are utilized as clothes lines or are used by the street urchins as kite traps.

They cross and recross the streets at every angle, every elevation, and at every tension. They are strung surreptitiously on poles to which no right exists, and over buildings for which no permit has been granted.

No one seem to have the power to compel a change or improvement in these practices, and the companies themselves never will do it until so compelled. The sharp competition in the lighting business, the small profits derived therefrom, the great trouble of hauling down and getting rid of miles of dead telephone and telegraph wires, all these interfere with a satisfactory straightening out of the existing system of overhead wires.

In all movements for public improvement we have to consider the arguments for, as well as against such improvements. It is not sufficient that we say that there are disadvantages attending the introduction of the system, we must consider likewise the possible advantages; and this is especially important when we consider the use of the overhead line in a system for propelling street cars. Such a line being part of an investment of a company which has practically no competition on its own streets, and whose own interest would require it to keep its line in first-class condition, can be put up in a manner presenting few of the

objections which are generally urged against a system of overhead wires. I would not urge its adoption for all places, but in all suburban districts, for comparatively narrow streets, for all streets operating under an elevated railway structure, or where the tracks are near a sidewalk, the direct system of supply from an overhead line with underneath contact, presents advantages which, once appreciated, far outweighs the possible objection of such a system.

Several methods exist in which the wires can be erected. One in which span-wires, at a distance of 125 feet apart, reach across the street from building to building, or from pole to pole, and have suspended from them directly over the track, at a height of about 19 feet, a longitudinal wire of not more than a quarter of an inch diameter, this wire being termed the "working conductor." This should be of the very strongest character. It should have a high elastic limit, great tenacity, and resist corrosion and oxidation.

Its conductivity is a matter of less importance, since not upon it, but upon the main conductor which supplies it do we depend for the main transmission of our current. Hence the elements of strength and reliability are of far more importance then conductivity. We have found that the best wire for this purpose is that alloy known as "silicon bronze"—a wire which can be drawn for a tensile strength of from 75,000 to 150,000 pounds per square inch; that is a strength higher than that of the best commercial steel. Such a wire it is almost impossible under conditions of service to break, and its life is very long. Samples of hard drawn copper wire, which possesses only from one-third to one-fifth the tensile strength of this wire, show, after months of severest usage, scarcely any signs whatsoever of abrasion, or reduction in size. This wire is of the same size whatever the distance run or the number of cars operated, and the main conductor may be stretched along the buildings, through a side-alley, along poles, underneath the elevated structure, or buried underground.

In the latter case there would be in a single track street only one longitudinal wire, and that one over the track, and it would be no longer than a single telegraph wire; and in the case of a double track, there would be only two wires stretched longitudinally along the street, and these would be as taut as harp strings.

Switches and cut outs are put in main, and working conductors in such a way that the different sections can be operated independently, and cut out automatically or at will.

The span-wires can be as much above 19 feet from the ground as is desired. Of course, where a telephone or electric light line crosses the street and may break and fall upon such a conductor, it would be necessary to have one or two guard wires above it.

These guard wires can be very properly carried from the span wires themselves. Furthermore, if desired, the stretches between the span wires where guard wires are used can be very much longer than 125 feet; they can be even as long as 500 or 600 feet—that is, two or three city blocks—in which case the two guard wires form a light suspending structure from which, at intervals of a hundred feet, the middle wire is carried in a straight line.

In very many cases it is unnecessary to have any span wires whatsoever. In those streets where the track runs near the curb a light pole with an ornamental bracket is all that is necessary.

In a broad street where the tracks occupy only a small portion of the street, and are near together, a line of poles of ornate design with light arms projecting on either side can follow the centre of the street. Oftentimes there is a middle division or park, such as exists on the Boulevard in this city, which will afford space for the poles without interfering with anything.

These same poles can be used for lighting the street.

On streets occupied with elevated railroad structures, the structure itself can be used as a support for the overhead wires.

Among the numerous places in New York where an overhead system could be put in perfect operation are Eighth Avenue, from Fifty-ninth Street up; the Boulevard from Fifty-ninth Street up; a part of the First and Second Avenue lines; the Third, Sixth and Ninth Avenue lines, and all the suburban extensions in the annexed district.

To avoid any extra strain on this wire, the current is taken off by a flexibly supported trolley carried on the car, and making contact underneath by upward pressure, as will be more specifically described later.

With such a system put up in the proper manner, it is almost impossible for any accident to occur which will disable the line or prove a hindrance or annoyance to the public in any way.

The wires are perfectly clear of the operations of the firemen, and should they in any place interfere, the obstructing section can easily be cut out without disabling the remainder of the system.

The question of the "electromotive force," or electrical pressure, so to speak, to be used, is one of great importance. I do not favor going above about 400 volts, and this on a continuous current circuit. This is less than one-seventh the electromotive force which exists on many of the arc-light circuits in this city; and the current being of a perfectly smooth and continuous character is free from the danger which might be feared from a current of equal electromotive force of the alternating or pulsating character.

In point of fact, in Richmond, a very large number of our men have received the full E. M. F. from our line without any injury.

On a dry day, the trolley wire has lain coiled up on the ground while the cars are in operation; and while certain changes were being made in the overhead circuit, the men worked continually with the current on the line. I have never known a constant potential current of 400 volts to cause of itself the death of or serious injury to a human being.

The past year to me has been one of great responsibility and wide experience. It has been a hard year. But the experience and expense are as nothing compared with the great value of having been with my associates instrumental in bringing to a successful issue one of the most important pieces of electrical engineering with which I have ever had anything to do. Among the roads which we have equipped the most important is, of course, the Richmond Union Passenger Railway, which now has six times as many machines in operation as any other road of its character in existence, at which every difficulty to be encountered in an overhead system on heavy grades and with sharp curves has been met, and which has for all time conclusively settled the question of the economical operation of a large road by the method of direct supply;

I will briefly refer to the road, giving some illustrations of its principal features, and some facts about its operation.

Some idea of the character of the road may be gathered from the following: The total trackage is about twelve miles. It runs a very irregular course and reaches the principal parts of the city. About nine miles of street are covered. The central section is a double track for a distance of something over two miles, a part being laid on paved streets, and the balance on macadam or unpaved streets, all the extension and branch lines are on unpaved streets, many of them in clay soil, which in wet weather covers the tracks, and where it would be an impossibility to oper-

ate horses without paving. The double track section partly encircles the old State Capitol, and presents difficulties rarely equaled elsewhere. This part of the line in a distance of less than one thousand feet has on both east and west-bound tracks, four curves, the inner rails of the west-bound track being of about 27, 30, 40 and 50 foot radius. The power necessary to run these sharp curves is much increased by the fact that grades are encountered on the curves as high as eight per cent., and the lay of the streets has required some of the outer rails to be some inches below the inner one. Running eastward from the Capitol the road descends to a low valley through a series of grades varying from three to ten per cent, and then ascends a series of sharp grades and curves in a new district to one of the car houses.

Going west from the State House the road rises to nearly the highest point in the city, and then runs through a residential district across the Richmond, Fredericksburg & Potomac Railroad, and after several sharp curves extends back a further distance of two miles to a second car house beyond the new reservoir. Two branches connect with its main line, one leaving at the old Market Place crossing, and paralleling the Chesapeake & Ohio Railroad, and terminating at its machine shops. The other runs into what is popularly known as "Africa," a section almost exclusively inhabited by colored population.

The narrow streets, their hilly character, and the lack of paving, especially in the new districts, has made the road one of exceptional difficulty to operate. There are no less than twenty-nine curves requiring bent rails, the majority being of sharp radius, five being less than thirty feet. There are also several sweeps or curves of larger radius, several turnouts and cross-overs. The grades are the maximum ever ascended in practice by a self-propelled car depending on track adhesion alone, and many of these grades are very long. Going east there is one section of almost continual ascent of about 5,600 feet, with grades varying from three to seven per cent., and going west there is a stretch of 1,900 feet, with grades varying from three to ten per cent.

When we first undertook to equip this road in the face of these difficulties, there was the additional discouragement of the ridicule of a great many prominent street railway men and car constructors as well as electricians. It was only a comparatively short time ago that one of the leading lights in street railway cir-

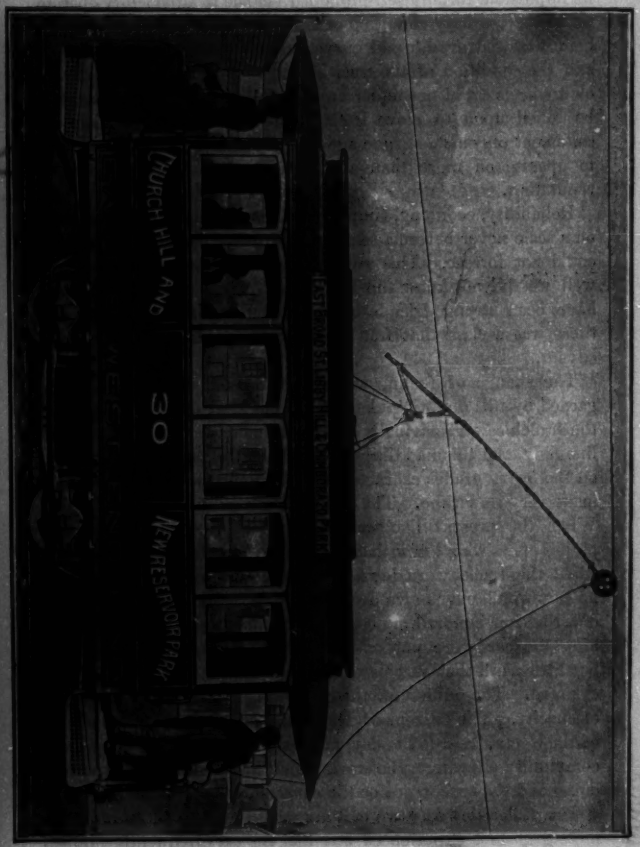


FIG. 8.—CLOSED CAR ON RICHMOND, VA. RAILWAY.

cles made a report to the street railway convention in which he stated that unless some new invention should be made it would be impossible for any self-propelled vehicle to satisfactory operate under the ordinary condition of street-car service. He, as others, held that the grades and curves met in practice were so severe and the condition of the track so bad that a car propelled by its own wheels could not under any possibility, day in and day out, be relied upon to move itself. One electrician even made the statement only a short time ago that any man who should attempt to operate on more than a six per cent. grade would lose his reputation.

Reliability, economy, simplicity of construction and operation on a scale never before attempted and under conditions which we could not foresee. This was the problem, and perhaps it was well we did not know the difficulties. Then again, while there have been strong friends of the enterprise in Richmond itself, there was a class that felt anything but pleasure at a stranger's advent.

The change of feeling with which this enterprise has been regarded by this doubting element is somewhat significant. When the franchise was originally secured the city was blest by one car-line only, and this had dingy bob-tail cars drawn by mules, which, on the heavy grades characterizing the topography of Richmond, made very slow time. The new districts were not reached at all. When the present line was proposed there were not wanting philosophers who knew that no road would be operated. Even when the tracks were down these same wiseacres predicted that no cars would ever move over them, and most certainly if they did, the time-honored mule would be called upon for duty. Even after the cars were put on the line experimentally there existed but little faith that success would be reached. But times have changed. The mules on the competing line are to give way to electricity. The citizens of Richmond are the strongest friends of the electric railroad to-day, and as regards the street railway community elsewhere, the work which the road has done and is doing and the acceptance of the contract, speak for themselves.

The difficulties we have met are many. One of the most annoying at first experienced was that the cars frequently jumped the tracks. A large portion of the track was, as has been stated, laid in macadam and dirt streets, the latter being chiefly in new districts and in a soil of which the chief component was red or

yellow clay, and although the curves were of sharp radius, only one guard rail was used, and this was not bound in by paving. The winter months brought frequent and heavy rains. The tracks were found to be settling out of sight in mud and especially at the curves they were spreading. The cars being large and heavy, with a 4 foot 8½ inch gauge and a 6 foot wheel base, helped to make the curves spread by the tangential pressure of the forward wheels on the outer rails. Mud and stones would get into the grooves, and the cars having a tendency to go ahead instead of being pulled around by the head as with horses, would climb the track, and before an inexperienced man could check them, the wheels were down five inches in the mud alongside the stringer pieces and the track brakes, hard and fast against the tracks. Sometimes it was lifting, sometimes prying, and sometimes a heavy hard pull on the part of the motors to get them back again. Experience, however, is a great teacher, and among other things which has been taught is this: that money will be saved by good track construction and the observance of a few practical points. All curves should be bound in and paved, and this has since been done in Richmond. They should likewise have two guard rails, because it is much easier to steer a car by its rear wheels by holding them in place, than by allowing them to crowd the inner rail and force the forward wheels to climb the outer one. In dry weather, with the large wheel base and sharp curves, it is found advisable to grease the grooved rails.

Another point which has to be carefully taken care of is the character of switch which is put in for sidings and cross overs. If drop switches are used, they should be of such character as to allow the car to come down easily; tongue switches are now being put in on all the new work which is being done. It is a rare thing at present to have a car leave the track. I have seen a car in the winter propelled for a hundred feet off the track, and also leave and go back on its own account.

The power house is situated two blocks away from the nearest point of the line, and is almost equi-distant from its extremities. As a distributing point, it is, therefore, both theoretically and practically, a central station. In the construction, no expense has been spared, and the performance of the station has justified it. The battery consists of three cylindrical return tubular boilers of the latest pattern, mounted on a Jarvis patent furnace, their capacity being 125 h. p. each. The water is taken from the city

FIG. 4.—CAR ON STEEP GRADE, RICHMOND, VA.

mains or from a well. All feed-water connections are of brass pipe. From the pumps the water passes first through the feed-water heater, where it is heated from 150 to 200 degrees F. From there it goes to the filter. The draft in the furnaces is regulated by an automatic steam damper regulator, which with anything like regular firing, keeps a pressure within two pounds of that for which the regulator is set.

The boilers all feed into one main feed steam pipe, which in turn leads to a separator, a large iron cylinder into which the steam passes, the water falling to the bottom and the dry steam being carried off at the top. All live steam pipes in the boiler room are covered with magnesia.

The present battery occupies less than half the available space in the boiler-room so that four more boilers can easily be put up when it becomes necessary to enlarge the plant. Two more have just been added. An important feature of these boilers, which are the source of power of the whole system, should not be overlooked, that is the quality of coal burned. Where a very perfect combustion is obtained a grade of coal can be used which would be impracticable in an ordinary furnace; the mixture at present being used is two parts screenings to one part bituminous, costing from $1.75 to $2. per ton delivered. As the station is only three hundred feet distant from the depots of three railroads, coal can be obtained almost at the door. From the boiler-room both the steam and exhaust pipes run in an underground, mineral-wool-packed trench to the engine-room.

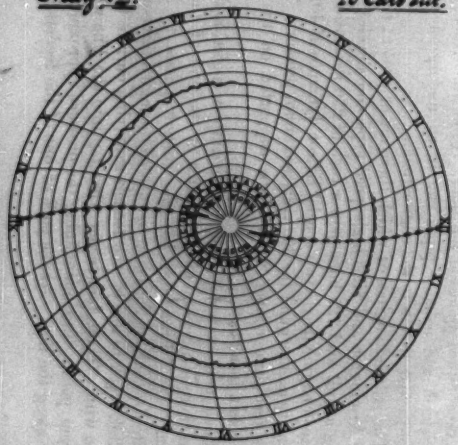
The railroad engines of which there are at present three, are of the Armington and Sims high-speed type, and develop when running at full load 125 horse-power each at 250 revolutions.

Each engine drives two special Edison dynamos of 40,000 watts capacity each, wound for 500 volts maximum pressure. The dynamos feed into copper "bus" bars, supported on the walls by porcelain insulators.

Each machine has its independent ampère meter, and in addition there is a general ampère meter at the end of the positive "bus" bar. From this bar the current passes to four snap switches, each switch being connected through a three-plug safety switch block to one of the feeders supplying current to the main line wire. These four-feeder wires tap into the line wire at different points, thus maintaining the pressure approximately equal all along the line. At the ends of one of the feeders in the cen-

Steam Diagrams of the Richmond Union Passenger Railway Co.

May 4th. 20 Cars out.



May 5th. from 20 to 30 Cars out.

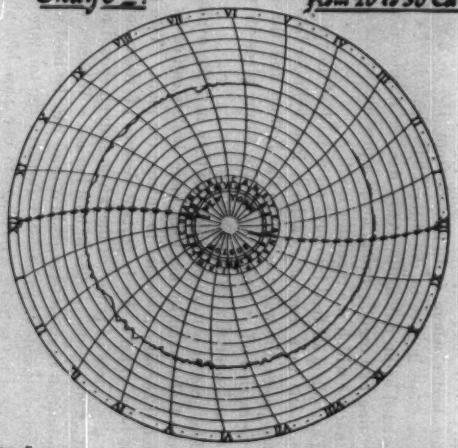


FIGURE 5.

tral station pressure indicators are to be attached which will indicate the voltage at the junction of one of these feeders with the main current wire, and this will serve as a guide.

The electric circuit consists of two parts—the overhead and the ground circuit, each being of compound character. Along the curb stones at distances of 125 feet are thirty-foot poles, inserted into the ground a distance of five feet. Great difficulty was experienced at first on account of the clayey character of the soil, and it became necessary to put in very heavy poles at the corners, which were imbedded in concrete and stones to prevent settling out of place after heavy rains. These poles carry the main circuit which extends throughout the entire length of the roads, and is a copper wire three-sixteenths of an inch in diameter; this is called the main conductor, for on it depends the operation of the road in case of accidents or repairs to the contact wire.

The arrangement of main and working conductor are as already set forth.

This main conductor is, as stated, supplied at widely separated points by feeders, which come from the main supply at the central station. Without the use of these feeders, which can also be reinforced if necessary, the size and cost of the overhead conductors would be very largely increased. The curves are formed of a series of short chords, which approximate the central line of curvature.

The current is taken from this working conductor by a light structure on top of the car. This consists of a low skeleton framework which carries an adjustable swivelling trunnion, having at its upper end a jaw in which is suspended a counter balanced trolley pole, having at its extension a grooved wheel held by a spring against, and making running flexible contact with, the under side of the working conductor. The flexibility of this arrangement is very great, it being able to follow with perfect facility variations of the trolley wire two or three feet in either horizontal or vertical direction, at any speed, and around any curve. What is all important, it relieves the line of strain instead of adding to it. When getting to the end of the track this trolley trunnion is swung around so as to trend in a proper direction abaft the centre of the car. If off the line it can be replaced from the car quickly and easily in the darkest night. From the trolley the current passes through a protected wire to the lightning arrester and thence to two switches, one at each end of the

car, whence after whatever commutation is necessary, it goes to the motor circuits, and thence to the wheel frame.

The return circuit is through the track, and thence by both metallic and ground circuits to the station. Each section of rail is joined to a copper ground wire, which runs throughout the length of the road underneath or alongside the stringer pieces, which is to prevent appreciable differences of potential existing between the rails; as a further precaution, at intervals of 500 ft. this ground wire is connected to an earth plate, and at seven points widely distributed, these ground plates are supplemented by heavy iron pipes sunk into iron ore, or 12 inch water wells, about 25 ft. deep. The ground wire is connected to the station, and there is also a main ground connection made there in a thirty-foot well through a large sink plate, and another to the entire water-works system. Some modifications of the overhead system are now being made which will make it impossible for any accident to one section of the line to disable the remainder; will enable the different sections to be operated independently; and, in case of a fire which may necessitate the blocking or temporary disabling of one part of the line, will allow this section of the line to be cut out of action either automaticaly or at will.

Each car is fitted with a duplicate and very powerful motor equipment. This is carried entirely beneath the car body, is very compact, out of sight, and necessitates no radical change in the construction of the car. The body had to be stiffened a little and 3-inch steel axles put in. One of the great objections which have been met with in applying motors, whether steam, electrical or of any other character, to the propulsion of street railways, has been the difficulty of getting sufficient track adhesion to operate the car under all conditions of track, loads and grades. Especially was this objection true in Richmond, where it was manifest that no application of a moter system could be fully successful unless the entire weight of the car and its contents was made available for traction.

One of the manifest reasons is, of course, the slippery character of the track under many conditions. Another thing should also be noted, and that is that it is almost impossible in practice to cast all wheels of exactly the same circumference, or at least so that the paths described by the lines of contact shall be the same. Moreover, on curves, the wheels are all traveling over paths of different lengths. Theoretically, the wheels should be inde-

pendently driven, but since this is not possible it follows that the next best thing is to drive each pair of wheels independently. It is a fact which admits of no dispute that there are conditions of track which will not permit of a car being driven from one pair of wheels only, and this difficulty is often augmented by the fact that if one pair of wheels only is used they will sometimes be leading, sometimes following; on heavy grades with one platform reserved for the driver there is a very serious displacement of the centre of gravity and there may be very much more weight upon one pair of wheels than on the other. The whole experience in Richmond has been to emphasize the value and necessity of independently driven axles.

To accomplish this, one motor is centered upon each axle, and to allow the required freedom of motion, and at the same time to preserve perfect parallelism in the meshing of the gears, and also for taking part of the weight of the motor off the body of the axle and to throw it on to the journals, one end of the motor is supported by double compression springs playing upon a loosely suspended bolt, which is supported from a cross girder in the bottom of the car.

The motors are, then, so to speak weighed or flexibly supported from the car body, and the motion of the armatures is transmitted to the axles through intermediate gearing, of compact form and great strength, so that whenever the axles are in motion there is a spring touch of the pinions upon the gears. Barring friction a single pound pressure exerted in either direction would lift or depress the motor a slight amount, and no matter how sudden the strain, whether because of a variation of load or speed, or a reversal of direction of rotation, it is impossible to strip the gears unless the steady strain exceeds the strength of the iron, the pressure on the gears always being a progressive one. The motor armature makes nearly twelve revolutions to each revolution of the car axle.

The motors, although in one sense independent, are connected with duplicate switches at either end of the car which afford simultaneous control of both machines. These motors, which are of normal capacity of 7½ horse-power each, can for a short time work up to 30 horse-power, and are capable of producing a tractive effort of over three thousand pounds at 50 per cent. efficiency.

The machines are controlled by a single movement switch

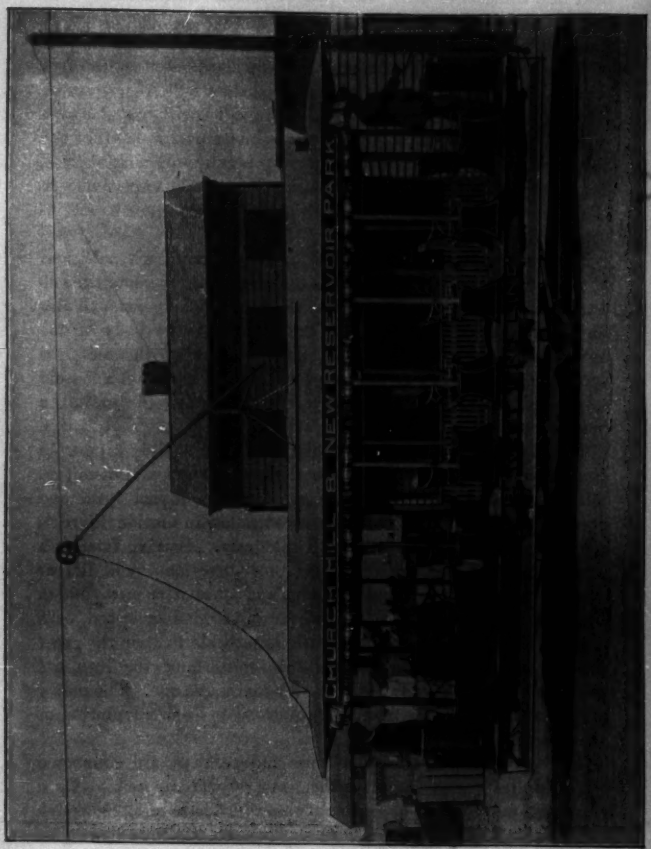


FIG. 6.—OPEN CAR ON RICHMOND, VA. RAILWAY.

which effects the various commutations and reversals. They run with fixed brushes in both directions and under all loads. They are run without any covering, and I have no doubt of having street car motors in such condition soon that the cars will be run over a pit, and the machines washed down with a hose.

The cars can be run at widly different speeds, varying from the slowest crawl to twelve or more miles per hour. They can be started and stopped without the use of brakes in the space of three or four inches, and when making the normal running speed can, in an emergency, be stopped and reversed without brakes within less than a quarter of a car length. The starting, although prompt, is easy and without shock or jar.

Emergencies sometimes bring out qualities of motors which are unexpected, or which at least if counted on are rarely ever brought into play. On one occasion a man was descending a six per cent. grade with a heavy load when his brake chain parted. Seeing a sharp curve right ahead of him which he knew he would leave if he struck it at the speed he was running, he instantly reversed his machines and brought his car to a standstill, and on the rest of his trip handled his machines entirely with the motors. On another occasion a man passing from behind one car directly in front of another was struck and knocked down by the dash-board. Although the car was moving at a lively gait, the machines were reversed and the wheels stopped within a foot of the man. By any other method of propulsion he would have been killed. Frequently on a ten per cent. grade, with a loaded car, the brakes have been thrown off, the machines reversed, the car stopped and started backward up hill within less than one-half of its length, a test of the most remarkable severity.

In noting the control of the car, one is struck at the remarkable character of the traction, and cannot help wondering where it comes from; unquestionably it is in a large measure due to the fact that every pound of weight is available for traction, and that the two axles being independently driven, can take their own speed, and each pair get the best grip.

Another thing to be noted, where the ground circuit is used, is the increase of traction due to the passage of the current from the wheels into the rails. Exactly what molecular action takes place has not been ascertained; it may be simply heating at the contact surface, but the fact remains that the traction is very largely in-

FIG. 7.—OPERATING WITH ALL CARS "BUNCHED" AT EXTREME END OF R

creased. The magnetic condition of the wheels and tracks also has some function in this increase of traction. The wheels and axles are magnetized by the method of motor construction and mounting, and also by the passage of the current through them; the tracks are likewise magnetized by the current passing through them and also by the rolling contact of the wheels. Yet, admitting all these aids, the results have been extraordinary.

Sixteen-foot closed cars carrying picked loads of fifty-five to sixty passengers, and having a total weight of 15,000 pounds, are operated on the 10 per cent. grade, often with a slippery and slimy rail, and on 27-foot curves, without the use of sand or extra help.

These same grades and curves have been ascended without sand after one of the worst sleet storms which has visited this section for years. Various tests under the most unfavorable conditions have been made, cars often being required to cut their way through clay, snow and ice when the tracks were out of sight. No severer test could have been made, and the power and tractive effort developed have exceeded the most sanguine expectation.

Cars have often been stopped and started on the heaviest grades, and in the sharpest curves. One motor has propelled two cars around sharp curves and up six per cent. grades. One car has pushed another of greater weight around the sharpest curves and up seven and eight per cent. grades both straight and combined.

I have no hesitation in saying that with a clean track, and with proper gearing, these cars could mount a 15 per cent. grade, depending on adhesion alone. During the four months operation, although there have been troubles and changes have been made while the cars were running commercially, no car has been pulled a foot by animal power; if any accident has occurred to a motor the car has gone along with one machine, oftentimes with heavy loads and on heavy grades, or in some cases has gone home in company with another car. One hundred and forty men who did not know the difference between a motor and a hand-saw, have been broken in to handling these cars; oftentimes with remarkably short training. Up to Saturday, May 4, the number of regular cars on duty had not exceeded twenty. On that day at 4 P. M., the hour when traffic becomes exceptionally heavy, we began putting out ten open cars, starting them from the eastern car-

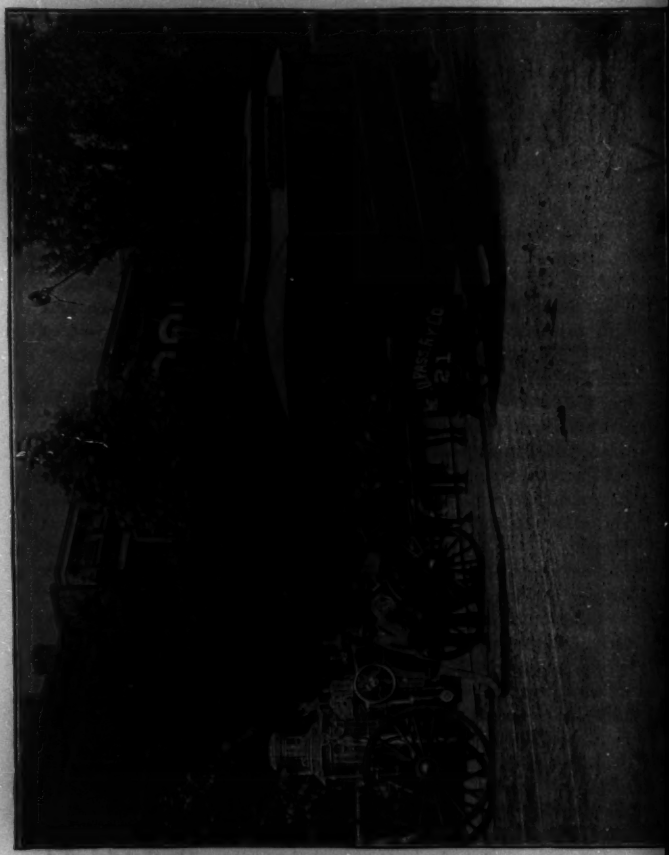


FIG. 8. METHOD OF JUMPING FIRE HOSE ON TRACK.

house alternating with the closed cars, but finally banking them all up at the Old Reservoir. At 6 P. M. they were started home, and shortly afterwards these ten open cars, headed by a closed car, were all run at full speed close together down the east-bound track of Clay street. At one time fourteen cars were on the line between Clay and Hancock streets and the Old Reservoir, and shortly before 7 o'clock there were about twenty-two cars on the line between Capitol Square and the Old Reservoir, and at 7 o'clock thirty cars were on the line, the closed cars being very heavily loaded, many of the cars being run with two minute intervals. The three boilers, whose capacity is 375 h. p., were then supplying three Armington and Sims engines of 125 h. p. capacity, which were driving the six railroad dynamos, and two Westinghouse engines of 110 h. p. capacity, which were driving two alternating current dynamos and exciters, with an equivalent load of 1,060 incandescent lamps. The mixture was enriched and the firing of boilers became pretty active, there being in addition to the thirty cars badly banked, about 110 h. p. taken for lighting.

The highest reading, however, on the line was less than three-quarters of the normal capacity of the dynamos, which were originally intended only for thirty cars, and the average reading for this number was only a trifle over half the normal capacity. Some idea of the effective work of the automatic steam regulator can be formed by an inspection of the steam diagram for May 4 and 5.

The ampère readings taken at intervals of ten and fifteen minutes give a load diagram which is really higher than a continuously recording instrument would show.

The figures which follow, being based upon an actual service increasing from eight to thirty cars, and extending over a period of four months under the most trying circumstances, and at the most critical and care-requiring period of the enterprise's existence, will give street railway men the most careful and liberal estimate of every possible expense attending the operation of the road which is in any way dependent upon its electrical features. The operating expenses are given under two heads; first, the central station operating expenses, and second, the road operating expenses, the two constituting the total cost of motive power. These are given in detail, and they will probably be found to cover every expense, although in some small ways the distribution of these expenses may be found to be changed by several

months longer running. The fuel and other incidental expenses of the station are from the engineers' record, and checked by the readings of the electrical instruments.

For thirty cars running on a double track the central station expenses are about as follows:

58 42-100 cwt. coal, at 10 cents	$5.84
113 70-100 cwt. screenings, at 7 cents	7.96
5 pints cylinder oil, at 75 cents per gal	.47
5 pints dynamo oil, at 30 cents per gal	.18
3 pounds of waste, at 10 cents	.30
Water at current rates	3.00
Fuel, etc	$17.75
1 day engineer	$3.00
1 night engineer	2.25
4 firemen	6.00
1 cleaner	1.50
2 dynamo men	3.50
1 electrician	4.00
Labor	$20.25
Lighting	.50
Depreciation and repairs on dynamos, 3 per cent	1.50
Depreciation and repairs on engine and boilers 10 per cent	4.38
Total central station expenses	$44.38

Or $1.48 per car making 80 miles.

[The central station being operated for twenty-four hours for lighting and power purposes, the lighting company has now assumed charge and rents the power to the cars at $1.60 per day.]

In estimating the road expenses more than liberal allowance is made, but in a new enterprise it is safe to err on this side rather than attempt to claim for a system advantages which will not in practice be borne out. The expenses are then as follows:

Oil, grease and waste	$4.50
Brushes	3.00
Trolleys	2.00
Material	$9.50

Three mechanics and one helper for thoroughly over-

hauling motors once a week, making repairs, adjusting brakes, etc	7.90	
Four inspectors, two day and two night, for oiling machines and looking after brushes	7.50	
Two night inspectors to thoroughly inspect motors after cars are laid up and see that all bolts, nuts and connections are tight and that everything is in good working order for the morning run	4.00	
One winder and helper for making any repairs which may be necessary and any testing which is required	3.50	
Two linemen	5.00	
Labor		27.90
Depreciation on car work at 15 per cent	18.00	
Depreciation on line work at 10 per cent	4.00	
Depreciation		22.00
Total road operating expenses		$59.40

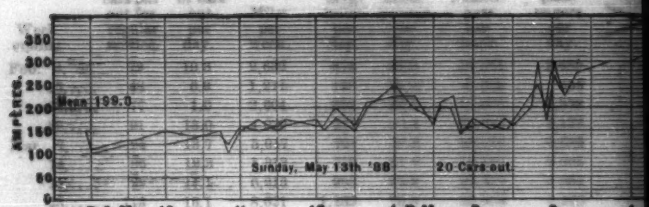
or $1.98 per car making 80 miles.

The total motive power expenses both in the central station and out on the road would not then exceed $3.46 per car making 80 miles, or 4.32 cents per car mile, and this includes everything except the executive and the salary expenses, taxes and insurance, and is less than 40 per cent. of the cost of operation by horses with the same number of cars, and under the same conditions.

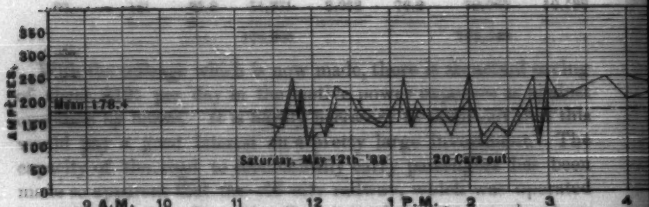
But the showing is even better than this, for another fact is to be noticed, and it is an important one from an economical point of view. For example, twenty cars on duty for about eighteen hours make a mileage of from 1,500 to 1,800 per day, and if it were not for the fact that the schedule requires them to operate part of the time on a single track with insufficient turn outs they could make 1,800 or 1,900 steadily. This, notwithstanding the fact that the speed is limited by municipal regulations. Many of the cars often run 90 to 100 miles. The same mileage and intervals made by twenty electric cars could not, under the circumstances, be made by anything less than twenty-five horse cars of the same size, and the electric cars probably carry in the aggregate just as many passengers. It follows that to get the same service with horses not only would the number ef cars have to be increased, but likewise the number of horses, conductors and

drivers. The same mileage performed by horses without motor cars and grades would require a stable equipment of not less than 300 horses.

A good idea of the operation of the system may be obtained from the following weekly table, taken from the records of the railway company up to the present date:



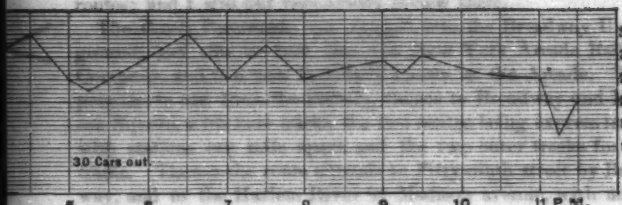
April 4.....	176	16.9	8,351	1,190	[illegible]	[illegible]	[illegible]
11.....	183	19.0	10,089	1,441	75.9	55,563	5,349
18.....	183	19.0	10,598	1,512	70.6	45,360	5,727
25.....	193	12.5	10,965	1,567	80.7	59,440	5,977
May 2.....	197	19.6	11,999	1,616	82.4	45,350	6,472
9.....	140	25.0	14,852	1,548	77.4	51,648	7,378
16.....	176	25.1	11,569	1,652	65.8	58,598	8,371
23.....	186	26.6	12,139	1,733	65.2	55,163	7,890
30.....	194	27.7	13,586	1,869	66.1	57,519	8,917
June 6.....	189	27.0	16,154	2,022	74.9	58,836	7,546
13.....	187	26.7	14,549	2,093	78.4	59,218	8,459

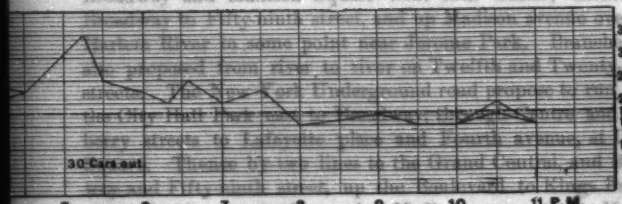


FIGS. 9 AND 10.—AMPERE DIAGRAMS WITH

by mules and has about 13 miles of track and 50 cars, has been bought up and is to be operated from the same central station. A third line will probably be added, and in the near future every other car, to the number of one hundred, in Richmond and Manchester will be electrically operated from one station.

From this same station a general power and light circuit,





TWENTY AND THIRTY CARS ON TRACK.

drivers. The same mileage performed by horses without these cars and grades would require a stable equipment of not less than 300 horses.

A good idea of the operation of the system may be obtained from the following weekly table, taken from the records of the railway company up to the present date:

Week ending	No. of cars put out for regular service.	Avg. No. of cars out per day.	Miles per week.	Avg. miles per day.	Avg. miles per car per day.	Passengers per week.	Avg. passengers per day.
Feb. 8, ...	72	10.3	2,632	376	36.5	18,764	2,680
15,....	48	6.9	1,211	173	25.2	6,688	956
22,....	77	1.0	2,604	372	33.6	16,504	2,358
29,....	91	13.0	4,039	577	44.4	22,944	3,135
Mar. 7,....	94	13.7	5,047	721	52.6	25,063	3,580
14,....	86	12.3	5,313	759	61.8	20,897	2,985
21,....	99	14.1	6,916	988	69.9	30,357	4.337
28,....	113	16.1	8,621	1,232	76.3	27,076	3,868
April 4,....	118	16.9	8,351	1,193	70.8	28,260	4,037
11,....	133	19.0	10,089	1,441	75.9	36,683	5,240
18,....	133	19 0	10,583	1,512	79.6	40,090	5,727
25,....	135	19.3	10,895	1,557	80.7	39,040	5,577
May 2,....	137	19.6	11,309	1,616	82.4	45,350	6,479
9,....	140	20.0	10,832	1,548	77.4	51,648	7,378
16,....	176	25.1	11,563	1,652	65.8	58,598	8,371
23,....	186	26.6	12,128	1,733	65.2	55,163	7,880
30,....	194	27.7	12,789	1,830	66.1	57,519	8,217
June 5,....	189	27.0	14.154	2,022	74.9	52,820	7,546
13,....	187	26.7	14,649	2,093	78.4	59,219	8,459
20,....	181	25.9	14,871	8,053	76.2	70,065	10,138
	...	....	178,906	.....	....	762,648	.....

With the mileage which is now made, there is an actual saving of about $125 per day in the motive power expenses as against operation by horses. It is hardly necessary to point out that this would pay a good interest on a pretty large investment. The capacity of the road to economically carry passengers has been made so apparent that the old city railway, which was operated by mules and has about 13 miles of track and 50 cars, has been bought up and is to be equipped with motors operated from the same central station. A third line will probably be added, and in the near future every street car, to the number of one hundred, in Richmond and Manchester, will be electrically operated from one station.

From this same station is operated a power and light circuit.

Having thus seen what is possible on a street railway, let us briefly consider the application of electricity on a larger scale.

The failure of the elevated railroads in this city to meet the issue of rapid transit is in no way more forcibly illustrated than by the number of plans which have been brought forward for discussion. No less than eleven have presented themselves, several of which have features in common and claim similar routes; and I will but very briefly review them.

The Beach Pneumatic was merged into the Broadway Underground, and this in turn into the New York Arcade Railway Company, and it is now familiarly known as the Arcade. They propose to run from the Battery, thence to Broadway and Madison Square, with four tracks, the two centre being express tracks, with stations one mile apart, and the two outer tracks for way traffic. Thence the route extends to Fifty-ninth street by Broadway, and to the Harlem River by Madison avenue, with an additional route up the west side of Central Park by the Boulevard or some other avenue, and into the annexed districts. Branches are proposed to connect Broadway and Madison avenue on Twenty-third street, and the two branch roads on Forty-second street.

The Underground Railway Construction Company has pooled the issues of the New York District, New York Underground and the Metropolitan Junction Company. The route of the first is similar to that of the Arcade and runs from the Battery to Broadway and Madison Square with four tracks; thence up Broadway to Fifty-ninth street, and up Madison avenue over the Harlem River to some point near Jerome Park. Branches are also proposed from river to river on Twelfth and Twenty-third streets. The New York Underground road propose to run from the City Hall Park east to Broadway, through Centre and Mulberry streets to Lafayette place and Fourth avenue, at Union Square. Thence by two lines to the Grand Central, and Broadway and Fifty-ninth street, up the Boulevard to Kings Bridge, the main line continuing under Madison avenue to the Harlem River and by a loop to Kings Bridge.

The Metropolitan Junction Company proposes to connect with the two last named in the annexed districts, and then run over the Hudson by a bridge at Washington Heights, connecting with a tunnel through the palisades.

The City Railway Company proposes to begin at South and Whitehall streets, crossing Broadway below Rector, running be-

tween Church street and College Place, Sixth and Seventh avenues to Fifty-ninth street and the Boulevard. The line would then run up the west side of Central Park, crossing the Harlem River above High Bridge, terminating in New Rochelle. Branches are proposed for the principal ferries on both rivers, the Post Office and Grand Central Station. The roadway is intended to be 50 feet wide and 12 feet below the street surface; it is to have four tracks, two way and two express. It differs from the other underground railways in that instead of taking the street lines it proposes to purchase the necessary property and erect buildings over the line of the road, which are to be rented for sufficient to pay the bonds of the company. The road thus running through the basements, so to speak, of the buildings, and crossing the streets by tunnels, becomes a covered roadway instead of an open one.

The Terminal Underground Railway Company proposes a four-track underground railway from the City Hall along the proposed Elm street improvement to the Grand Central Depot.

The Metropolitan Transit Company proposes two elevated steel structures, one on Broadway, between Chambers street and Forty-third street, connecting with the Grand Central Depot, and the other on the West side following the line of the water front to Gansevoort Market, thence up Tenth avenue and the Boulevard to Kingsbridge.

The plant proposed by Heman Clark is one of the most radical. He proposes a four-track tunnel, beginning near Fleetwood Park, cut in solid rock 150 feet below the surface, coming down about 100 feet west of the line of Broadway to the Astor House, where it would connect with two two-track branches, one going under the North River to Jersey City and Newark, and the other under the East River to Brooklyn and Prospect Park. Passenger stations would be at the foot of shafts sunk every two miles, and freight stations at intermediate shafts where freight pockets would be tunneled. Large elevators would be used for handling the passengers and freight.

All of these schemes have their good and bad points which I do not propose to here discuss; but whichever is successful, they hope to use electric motors for propulsion. Now whatever we claim for electrical motors, it would be folly to attempt the handling of the traffic of such a road without full knowledge as to the character of the work which has to be performed and a perfectly

definite idea of the system of train dispatching which will best meet the wants of the public, and, at the same time, preserve an effective and economical system of operation. To fully consider this let us briefly review the work which is being done on the elevated railroads, for example on the Third avenue line.

This is eight and a half miles long. Grades vary from eight to one hundred and five feet to the mile. The level stretches amount to about one-third of the whole distance, and this includes the stations. On the seventeen miles of single track there are fifty-two stations. In the busy hours there are no less than sixty-three four and five-car trains on the tracks. These trains weighing from eighty to ninety-five tons, make the half trip in forty-two minutes, including stopping at twenty-six stations and discharging and taking on passengers, or at the rate of about ten traffic miles per hour. The work of the engines, which may be divided into three parts, overcoming the train's inertia, lifting the train on the grades and traction, and the maximum is at least seven times that necessary for traction at mean speed on a level. Three times in every mile this weight of 80 to 95 tons must be started from a dead rest, raised to a speed of twenty or more miles an hour and brought to rest in about eighty seconds. The engines have to be run with 130 pounds boiler pressure, and have a capacity of 185 h. p. Fifty-nine per cent. of the power on a round trip is used in starting, 24 per cent. in lifting, and 17 per cent. in traction, and the average power developed per minute per round trip, including stoppages, is 70.3 h. p.

The traction necessary to handle these trains is obtained by a locomotive weighing 22½ tons, of which only 15 are carried by drivers five feet apart. With an engine and the forward trucks of one car between two girders, we have a weight of nearly 1,500 pounds per running foot. The present weight of engines is not sufficient to properly handle these trains when the tracks are in a slippery condition, and it is not wise to increase it. It is absolutely necessary to keep up the high character of the engineering work of this road, and every consideration of business prudence and public safety will permit of no laxity in this direction. Yet these locomotives have done wonderful work. Although on duty for twenty hours, with steam admitted to the cylinder for six hours only, with an average horse-power of only 38 per cent. of the maximum, and with all the incidental losses of steam, they develop a horse-power with less than a total ex-

penditure of 6.2 pounds of coal per hour; and the coal expense alone is only about $1.15 per round trip, or $2\frac{1}{5}$ cents per train station. The operating expenses are 62 cents per train mile; or, allowing an average of four cars per train, 15½ cents per car mile; and this includes everything.

The percentage of expenses of operation and maintenace for the whole Manhattan system may be roughly expressed as follows:

Motive power	42.8
Maintenance of cars	5.4
Movement of traffic	38.4
Maintenance of way	8.2
General expenses	7.2
Total	100.0

The coal costs over $700.000 per annum, which is more than the wages of the engineers and firemen, but it is only about one-sixth of the total operating expenses. Hence there are other reasons than merely a saving in coal which must be urged in favor of an electric system as against a steam system.

Generally speaking, the real needs of rapid transit are not best subserved by the handling of long trains from a single tractive engine. True, the conditions of service on the elevated railroad, the crowded condition of the track, and the great cost of operating independent steam engines makes it impracticable to work with small train units there. But the fact remains that the effective length of train which can be operated by any system is limited; that this limit has already been reached on the elevated railroad, where only one-sixth of the weight is now effective for traction; and that the smaller the units the less the momentum of the train, and the easier it is to quickly and efficiently handle it and the less will be the liability of, and danger from, any derangement of the brake apparatus. Furthermore, the thrust of the moving weights on the grades, the vibration due to the shifting of the weight along the girders, the tensile, shearing and crushing strains on the structure are all materially increased by the use of a heavy locomotive at the head of a long train.

But since we must endeavor to meet all conditions of engineering, we must try to meet that one which requires the operation of a heavy train by a single motor car. In this case I deem it advisable to make the motor car of about the same size as the

cars which form the train, equip both trucks and thus spread the weight used for tractive purposes over a larger distance. We have now partly constructed a 300 h. p. motor equipment of this character.

This car, whose general external dimensions are similar to those of the regular elevated passenger coach, differs in its construction in many important details. The front and rear platforms are inclosed, and about ten feet at each end of the car—that is, the space over the trucks—is partitioned off and reserved for the use of the motor man. The middle space has side entrances, and is fitted for passenger accommodation. At each end of the car the floor framing is raised about twelve inches for a distance of about ten feet from the end, and the car body is carried on two very strong and heavy special iron trucks mounted on forty-two-inch wheels fitted with five-inch steel axles. Each axle has an independent movement and is driven by a tandem motor, centred upon the axle, which bears a part of the weight. The motor is also carried by heavy compression springs hung from the truck, by means of which as much of the weight of the motor as is desired can be thrown on to the boxes. Each motor, which is about 75 h. p. normal capacity, has two armatures, each of which is connected to a fixed and adjustable gear on the axle, the ratio of the gearing being about 1 to 3. These motors will have one brush on each commutator, and that will be a top brush. Each motor has directly over it, in the engineer's room, trap-doors fitted with heavy glass panels, which allow the machines to be seen at all times, and through which the machines can always be reached. The controlling devices and switches are all duplicates, and the car can be handled from either end. The car and the trucks are completed; the motors are well under way. The car will be capable of exerting a tractive strain of at least 20,000 pounds—more than double that of the present locomotives.

But that is not the ideal method of traction.

By a system of electrical propulsion, the power can be distributed underneath the cars, every car, or every two cars if need be, being a unit; and, although I do not think it advisable, arrangements could be made for propelling a large number of cars under simultaneous control. By distributing the power under the car, the whole weight of the car and passengers can be made effective for traction. This will enable the cars to be started more promptly, brought to speed more quickly, and stopped in

shorter intervals, increasing the mean rate of speed for a given maximum, or vice versa, reducing the maximum for a given mean rate. By making cars individual units of locomotion, the intervals between trains may be made one-fourth or one-fifth of the schedule which must exist where four or five-car trains are used. It may be said that this will increase the number of employés that are necessary. This is true, but it will increase the number of passengers who, both day and night, would make use of the system, in such a ratio as would make this increase of expense insignificant.

Let us consider a possible system which would go a long ways towards solving the question of rapid transit. I will briefly point out its features. It would have four tracks extending from the Battery up Broadway to Twenty-third Street; thence diverging in two divisions, each still with four tracks, one along the line of Madison Avenue to the Harlem River and terminating near the Jerome Park district; the other following Broadway and running up the line of the Boulevard and Tenth or Eleventh Avenues. Two tracks would be reserved for express traffic, with stations a mile apart, and two for way traffic, with stations every third of a mile, every third way station corresponding with an express station. The tracks would be arranged in two tiers, the express tracks being the lower. The entire system would be lighted, ventilated and operated by electricity, to be supplied from four stations on the water front, one at the Battery, one at East Twenty-third street, one at Madison avenue crossing of the Harlem River, and one on West One Hundred and Twenth-fifth street; the stations to be operated by compound condensing engines in three units connecting directly to large, slow moving multipolar dynamos, two engines being of sufficient capacity to handle the demand made upon any station; trains to be operated with one, or at most two car units; motors to be on the trucks of one car, centred on the axle and with one reduction of gearing; express speed to be thirty miles an hour, and way trains to make twelve traffic miles per hour; the current to be delivered to the cars by an overhead system with underneath contact, the contact wheel to be carried on the car, supported over the centre of the truck and trending a little abaft it. Freight pockets at the level of the way track could be run under the cross streets at express stations. Track to follow a line of grade of not more than 25 per cent.; access to stations to be by stairways, and where there is any

material difference between the street level and the track, by hydraulic elevators, operated from constant pressure tanks kept supplied automatically by motors. Freight trains to be run on way tracks.

Supplementing this system should be a line of surface cars, likewise operated by electricity from the same general source. In the heart of the city these can be operated from a conduit, or by the storage battery, and in all the suburban extensions by the overhead line system.

The objection of loss in transmission and recovery has been raised as against an electric system, and also the question of braking. These are easily met.

We have systems of electrical braking a train by the use of its motors, which consist in converting them into dynamos, deriving their driving power from the train, and using up its energy by converting it into electrical energy, which can be used in a variety of ways. In a storage battery system the energy of the car can be made to partially recharge the batteries on a down grade, and in stopping. In a direct supply multiple-arc system, operating a large number of cars, this power of being able at will to convert the energy of a moving train into electrical energy delivered to the line by the same apparatus which controls the speed and power of the train, is of exceptionable importance. In a double track system, the energy given to one track may be communicated to the other just as efficiently as along itself. In fact in the entire electrical system every part is mutually connected, and there is a bond of union between the different trains far more perfect and effective than any mechanical connection could be. The up-grades on one track being equal to the down grades of the other, it is evident that the total up-grade of a system is equalized by the down-grade thereof. If, then, energy is expended in getting under way and climbing up-grades, and a large proportion of this can be recovered in stopping and in running down grade, it is evident that the total initial energy required would be that necessary to remove the trains continuously on level grades, with a percentage for loss in conversion and reconversion added. The more train units which are operated, and the more frequent the stoppages, the more marked is this advantage in an electric system.

I some time since made a number of determinations of a system of the equipment capacity of the Third Avenue Elevated, in

which I found that about 40 per cent. of the power could be saved by this system of braking, where every motor coming to a station or running on a down-grade is made a generator which is helping to supply the current needed to operate the remaining trains.

Instead of the current being all supplied by a main generating station at one or two points, it would be supplied from nearly as many moving stations along the line as there would be trains slowing down or running on a down-grade. In fact, the loss of the two conversions and one transmission would be more than counter-balanced, and consequently the original horse-power at the central station would be no more than the aggregate net horse-power now developed on the entire line, and this is only about 38 per cent. of the total capacity of the engines. With any given potential and losses on the line, the main conductor would be very much smaller. Not only on the line, but at the central station would be a saving affected; for in a system of the capacity of that which we are considering this saving on lots, buildings, boilers, engines, dynamos and fittings would be not less than $400,000, and there would be about 40 per cent. saving in the coal, labor, deprecation and incidental expenses of the central station.

Another method of using the motors for braking purposes is to break the connection from the line and reverse the machine through a local circuit on the train, varying either the local circuit or the circuits of the machine. While in this position of breaking, if the local circuit is opened and the line connection made the machine would be instantly reversed.

Elaborate experiments were made by me nearly two years ago on the Thirty-fourth street branch of the New York Elevated Railroad, in which these questions of gearing, of mounting the motors on trucks, under the car and handling the car without shoe-brakes were very thoroughly studied. There this method of braking was shown to be under the most perfect control. When desired, the braking could be made so sudden as to cause the wheels to have a continuous skidding rotation, not such a skidding as is caused when an air brake is put on too sharply, but a rotating slip which is just enough to relieve the armature when the strain on it reaches the point determined by the co-efficient of adhesion on the rails.

This is the ideal method of braking, because fixed skidding

and flat wheels are an impossibility, and the wheels will turn until the train comes to a dead stop, although, where the braking power is put on too suddenly and exceeds the grip of the wheels, they will relieve themselves by slipping just enough to keep the braking at the maximum limit. A train so governed can be made to creep down the maximum grade of a road at a snail's pace, and in an emergency such a car, running 21 miles an hour on a down grade, has been stopped and reversed within 90 feet.

When an electric motor is reversed its action is cumulative, for so long as its motion continues in its normal direction, it tends to augment the current which flows through it with any given setting of the switch, and thus very much increases the effort to stop itself; and the higher the velocity at which the armature is traveling, the greater this effort. In fact, it would be practically impossible with a properly constructed railroad motor to prevent its reversing when the switch is thrown over far enough. This is another point in which an electric motor has a great advantage over a steam engine.

So it would seem that electricity has practical advantages over steam for this character of traffic, and there are considerations other than purely engineering ones. The use of electricity instead of steam would do much towards making a road of this character popular. We would have express and way trains, starting and stopping smoothly and quickly, moving at a high rate of speed and running at short intervals. Dust, smoke, cinders, oil and drippings would disappear; the air would be purer and cleaner. The train would be safer and under more perfect control; motive power would cost less; depreciation on the track structure would be much less; the carrying capacity would be increased; cars would be brilliantly lighted; comfortably heated; in short, everything which would make rapid transit safe, pleasant and effective is possible by a properly developed system of electric traction.

One of the most important sources of revenue from such a system would be the sale of power for stationary purposes. Already we are operating no less than 130 different industries by electric motors, and the receipts vary from $60 to $150 per horse-power. The extent of the application of electricity with any such general source of supply can hardly be conceived. Its profits would be far more than enough to pay the total cost of motive power.

But we must not shut our eyes to the work which has got to

be done. We must not exaggerate the advantages of electricity; we must not belittle the position of a system which has been developed by the ablest engineers for the last forty years. All their experience, all their study, all their victories form a magnificent groundwork for us to build upon, and will render the final victory of electricity more easy and certain if we build wisely and take to heart all the lessons which their years of experience teach us. In a small fraction of the forty years which have marked the development of steam engineering, electric engines will rival, in mechanical perfection, in construction and performance, the best locomotives. Even to-day, weight for weight, and duty for duty, the electric motor is already rivaling and outstripping its predecessor. For the present and for a long time to come it is probable that for trunk line work, and for the original source of our power in an electrical system, we will be dependent upon the steam engine, but we all hope and expect that the future will bring us some other effective means of converting the energy of coal into electrical energy, and that by some direct method which will not require the intervention of a steam engine and dynamo. It is not too much to hope for, and already experiments have been made which foreshadow this great result. The success of this discovery would produce such a revolution in the use and distribution of power as to exceed our most sanguine expectations.

THE PRESIDENT:—We have all listened with great pleasure and profit to the very able, interesting, and instructive paper of Mr. Sprague's, and as the hour is now late, I suppose we cannot enter into any extended discussion upon it to-night. I think it would be very proper to pass a vote of thanks to Mr. Sprague for the pains and care he has taken in presenting these matters to us, and furthermore for the extreme freedom with which he has spoken of his difficulties. It is a great indication of a growing art when electrical people can get together and discuss questions in which they are interested. For many years past there has been a feeling of seclusiveness among electrical engineers, which has been unfortunate. Such papers as we are having presented to us from time to time, indicate that that period has passed. The subject of electrical propulsion, as you are all well aware, has received much attention during the past

few years. Its rapid growth is astonishing, when compared with the growth of steam engineering. It is really very marvelous indeed. We have had presented to us to-night, a general scheme of electric railroads as applied to Richmond, Va. Those who know some of the difficulties that Mr. Sprague has had to encounter in this undertaking, cannot refrain from complimenting him most highly, first, upon his courage and perseverance and, second, upon his skill in overcoming the difficulties. (Applause.) The difficulties are much more serious than they appear to us on paper, and I can fully appreciate what it is to deal with such a problem. That Mr. Sprague has met with such success, and has actually received his pay for a railroad of that magnitude, running 30 cars, is I think a strong indication of what we may expect in the future.

Upon motion, a vote of thanks was then unanimously rendered to Mr. Sprague.

Mr. Sprague:—I regret the time is so limited as to prevent a general discussion of the paper this evening, as I fully realize that the suggestions which others may make, are oftentimes the highest possible aid. I would not be just if I should accept to myself the kind remarks which President Weston has made. The success of the Richmond Railroad is due to the courage, zeal and constant work, day and night, of the gentlemen who have been associated with me. I have had associated with me Messrs. Green, Crosby and others, who have been on the ground, and who have done everything to strengthen my efforts when I was not able to give attention to the business myself. Of course we have made mistakes, and will probably make a great many more, and if time permitted this evening, I would have been happy to have gone into detail on the difficulties which I met with. Sometimes it is like a nightmare when I think of it; but they were difficulties which we were obliged to meet and overcome difficulties which could not be foretold, and which had to be met as they came up. I thank the Institute again for their kindness. (Applause.)

Reference List of Leading Authorities Cited in the Index of Current Electrical Literature.

NAME.	ABBREVIATION.	PUBLISHED, &c.
Engineer.	*Engr.*	London, 163 Strand, weekly. £1.9.
Engineering.	*Eng.*	London, 35–36 Bedford St W. C.; weekly. £1.16.
Industries.	*Indust.*	Manchester, 70 Market St., weekly. £1.12.
The Electrician.	*Lond. Elecn.*	London, 1 Salisbury Court, E. C.; weekly. £1.2.
The Telegraphic Journal and Electrical Review.	*Lond. Elec. Rev.*	London, 22 Paternoster Row, E. C.; weekly. £1.1.8.
The Electrical Engineer	*Lond. Elec. Engr.*	London, 139–140 Salisbury Court; monthly. 3d. per issue.
The Telegraphist.	*Telegraphist.*	London, 74–76 Great Queen St., W. C.; monthly, 2d. per issue.
Nature.	*Nat.*	London, 29 Bedford St., W. C.; weekly, £1.8.
Knowledge.	*Knowledge.*	London, 39 Paternoster Row; monthly, 6d. per issue.
India Rubber & Gutta Percha & Electrical Trades Journal.	*I. R. & G. P. Jour.*	London, 115 Finsbury Pavement, E. C; monthly. 15 shillings.
The Electrical Engineer	*N. Y. Elec. Engr.*	New York, 11 Wall Street; monthly, $3
The Electrical World.	*Elec. World.*	New York, 168–177 Potter Building; weekly. $3.
The Electrical Review.	*N. Y. Elec. Rev.*	New York, 13 Park Row; weekly. $3.
The Electric Age.	*Elec. Age.*	New York, 5 Dey Street; semi-monthly, $1.50.
Modern Light and Heat.	*Md Lt. and Ht.*	Boston, 178 Devonshire St.; weekly, $3.
Western Electrician.	*West. Elecn.*	Chicago, 6 Lakeside Building; weekly, $3.
Journal of the Franklin Institute.	*Jour. Fkln. Inst.*	Philadelphia, Franklin Institute; monthly, $5.
Science.	*Science.*	New York, 47 Lafayette Place, weekly, $3.50.
Scientific American.	*Sci. Am.*	New York, 361 Broadway; weekly, $3.
Scientific American Supplement.	*Sci. Am. Supp.*	New York, 361 Broadway; weekly, $5.
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American Machinist.	*Am. Mach.*	New York, 96 Fulton St.; weekly, $2.50.
Street Railway Journal	*St. Ry. Jour.*	New York, 113 Liberty St.; monthly, $2.
Street Railway Gazette.	*St. Ry. Gaz.*	Chicago, 9 Lakeside Building; monthly, $2.
Light, Heat and Power.	*Lt. Ht. and Pr.*	Philadelphia, 413 Walnut Street; semi-monthly, $3.
Progressive Age.	*Prog. Age.*	Philadelphia, 333 Walnut St.; monthly, $2.
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Novel Current Registering Instrument. *Science*, June 15, p. 284. (Thomson.)

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A Galvanometric Battery. (Ill.) *Eng.*; *Elec. World*, June 16, p. 302. (Cooke.)

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The Electrolysis of Mercury. (Corr.) F. Higgins. *Lond. Elecn.*, June 15, p. 188.

The Electrolysis of Mercury by the Action of an Alternating Current of Electricity. Lowrie-Hall. *Lond. Elecn.*, June 8, p. 157; *Md. Lt. & Ht.*, June 21, p. 640; *Indust.*, June 15, p. 597; *Lond. Elec Rev.*, June 8, p. 635; *Elec. World*, June 30, p. 333.

The Copper Accumulator. *L'Electricité; Lond. Elec. Engr.*, June 15, p. 566.

An Improvement in Secondary Batteries. (Sellon.) *Science*, June 15, p. 284.

The Carrière Accumulator *Science*, June 1, p. 263.

Report of Prof. Kohlrausch on the "Tudor" Accumulator. *Lond. Elecn.*, June 15, p. 180; *Science*, June 29, p. 307.

New Types of Storage Cells. (Note.) *Lond. Elec. Engr.*, June 15, p. 556.

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The Management of Accumulators. (Corr.) Sir. David Salomons, *Lond. Elec. Rev.*, June 22, p. 687.

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Practical Notes Concerning the Construction, Use and Management of Storage Batteries. A. Reckenzaun. *Lond. Elec. Rev.*, June 22, p 665.

UNDERGROUND WIRES.

Underground Electric Conductors in Europe and America. G. W. Plympton. Am. Inst Elec Engrs *Lond. Elec. Engr.*, June 15, p. 563; *Lond Elecn.*, June 8, p 143; *N. Y. Elec. Engr*, June, p. 260.

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The Interesting Discussion of the Wire Problem in New York. *N. Y. Elec. Rev.*, June 9, p. 7.

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Letters for Learners and Unprofessional Readers. H. D. Wilkinson. (Cont'd from p. 48.) *Lond. Elecn.*, June 8, p. 146; June 22, p 210; June 29, p. 246.

A New Insulating Compound. *Chronique Industrielle; Elec. World*, June 16, p 304.

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Railway Accidents. (Corr.) W. R. Sykes. *Lond. Elec. Rev.*, June 1, p. 611.

Notes on Electrical America. J. Swinburne & R. P. Sellon. (Concl'd from p. 571.) *Lond. Elec. Rev.*, June 1, p. 590.

Special Magneto Bell. (Ill.) *West. Elecn.*, June 30, p. 317. (Ry. Tel. Sup. Co.)

Dynamo Tenders' Hand-Book. V. F. B. Badt. *West. Elecn.*, June 16, p 296.

Electrical Scale. (Ill.) *West. Elecn.*, June 2, p. 277. (Elec. Advtg. Scale Co.)

Death of Sir Charles Bright. *West Elecn*, June 2, p. 269

The Electric Resistance of Copper at Low Temperatures. *Eng.*, June 22, p. 625.

The Thomson-Houston Electric Company. *Eng.*, June 8. p. 558.

Electricity in the Navy. (Note.) *Indust.*, June 1, p. 554.

An Electric Organ. *Indust.*, June 1, p. 546.

A New Electric Regulator. (Ill.) *Sci. Am. Supp.*, June 30, p. 10,416

Papillamatous Tumor of the Bladder Demonstrated by Means of Lester's Electrocystoscope. (Ill.) F. N. Otis. *Sci Am. Supp.*, June 2, p. 10,354. Dr. Max Nitze. June 2, p. 10,353.

Progress of Electrical Science. *Sci. Am*, June 2, p 340. (Elisha Gray.)

Execution by Electricity. (Ill.) *Sci. Am.*, June 30, p. 407

Woodhouse and Rawson's Switch-Board. (Ill.) *Lond. Elec. Engr.*, June 1, p. 519.

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Acid or Resin for Wire Joints. (Note.) *Md. Lt. & Ht.; Lond. Elecn.*, June 22, p. 201.

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Magnetism in Watches. Theo. Gribi. *Am. Jeweler. N. Y. Elec. Rev.*, June 9, p. 10; *West. Elecn.*, June 23, p. 311.

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Another Electric Alarm Clock Arrangement. *Elec. World*, June 16, p. 308.

The Eco-Magnetic Clock. (Ill.) *N. Y. Elec. Rev.*, June 16, p. 1.

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The Patent Court and Uniformity in Patent Office Practice. G. H. Stockbridge. Am. Inst. Elec. Engrs. *Elec. World*, June 2, p. 283; *N. Y. Elec. Engr.*, June, p. 257.

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The Protection of Buildings from Lightning. Dr. Oliver Lodge. *Lond. Elecn.*, June 22, p. 204; June 29, p. 234. *Lond. Elec. Engr.*, June 22, p. 594; June 29, p. 613.

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Welding Rails by Electricity. (Corr.) O. K. Stewart. *N. Y. Elec. Engr.*, June, p. 268.

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Notes on Induced Currents. (Ill.) G. Doyle. *Md. Lt. & Ht.*, June 21, p. 641.

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The Theory of Diamagnetism. *Cosmos; Elec. World*, June 16, p. 306.

The Conductivity of a Vacuum. *Wiedemann's Annalen; Elec. World*, June 23, p. 315; *Lond. Elecn.*, June 1, p. 105; *Science*, June 29, p. 308.

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Electric Oscillations. (Ill.) (Corr.) F. Higgins. *Lond. Elecn.*, June 1, p. 126; June 8, p. 156; June 22, p. 220.

Irreciprocal Conduction. W. W. H. Gee & H. Holden. Phys. Soc. *Lond. Elecn.*, June 15, p. 184.

Method of Comparing Very Unequal Capacities. Dr. A. H. Fison, Phys. Soc. *Lond. Elecn.*, June 22, p. 215. *Lond. Elec. Engr.*, June 15, 574.

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On the Formulæ of Bernouilli and Haecker for the Lifting Power of Magnets. S. P. Thompson. (Lond. Phys. Soc.) *Elec. World*, June 30, p. 333. *Lond. Elec. Engr.*, June 8, p. 548.

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A New Frictional Machine. *Sci. Am.*, June 2, p. 341. (Tudsbury.)

The Wimshurst Electric Machine. (Ill.) *Sci. Am. Supp.*, June 2, p. 10,352.

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LORD BACON.